Curiosity's Mars Hand Lens Imager (MAHLI) in Gale crater

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Mars Hand Lens Imager
(MAHLI)
Mars Science Laboratory

Malin Space Science Systems

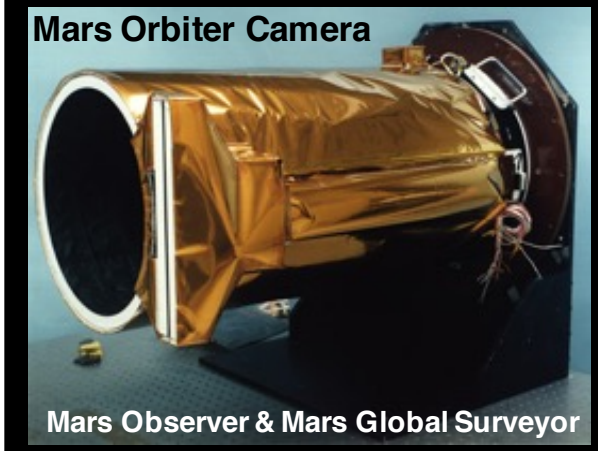
February 2017

We Build & Operate Space Cameras in San Diego

Malin Space Science Systems

www.msss.com

Mars Orbiter Camera



Mars Observer & Mars Global Surveyor

ASU

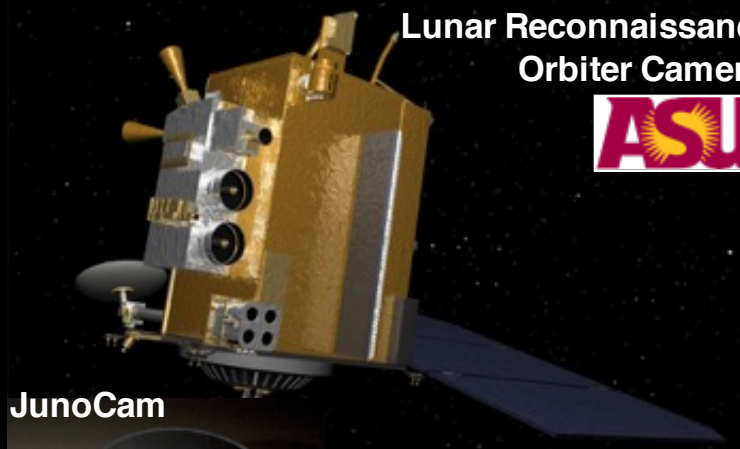
THEMIS VIS Mars Odyssey

Mast Camera, Mars Hand Lens Imager, Mars Descent Imager

Engineering Cameras

Lunar Reconnaissance Orbiter Cameras

ASU



JunoCam

OSIRIS-REx TAGCAMS

Psyche cameras

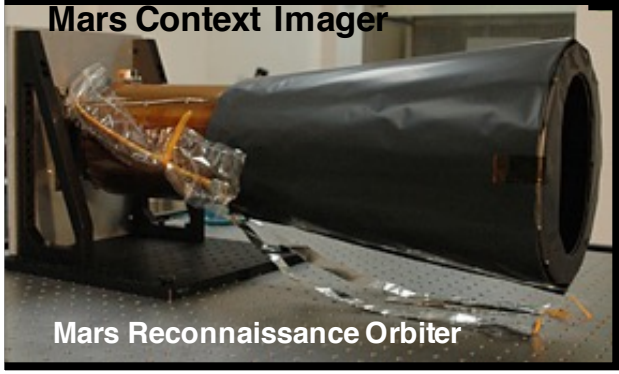
ASU

Mars 2020 rover

ASU

- Mastcam-Z
- SHERLOC/WATSON
- descent cameras

Mars Context Imager



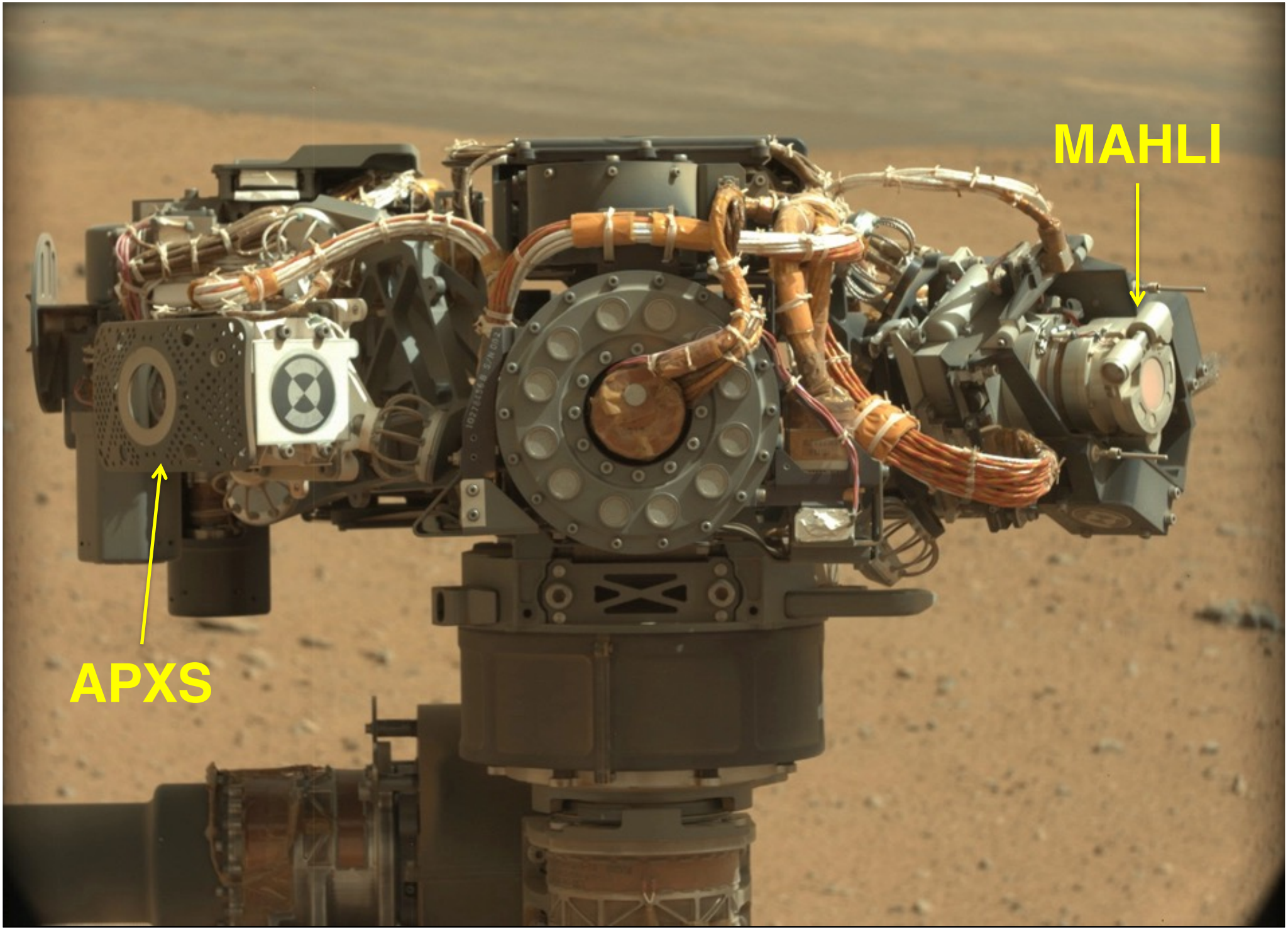
Mars Reconnaissance Orbiter

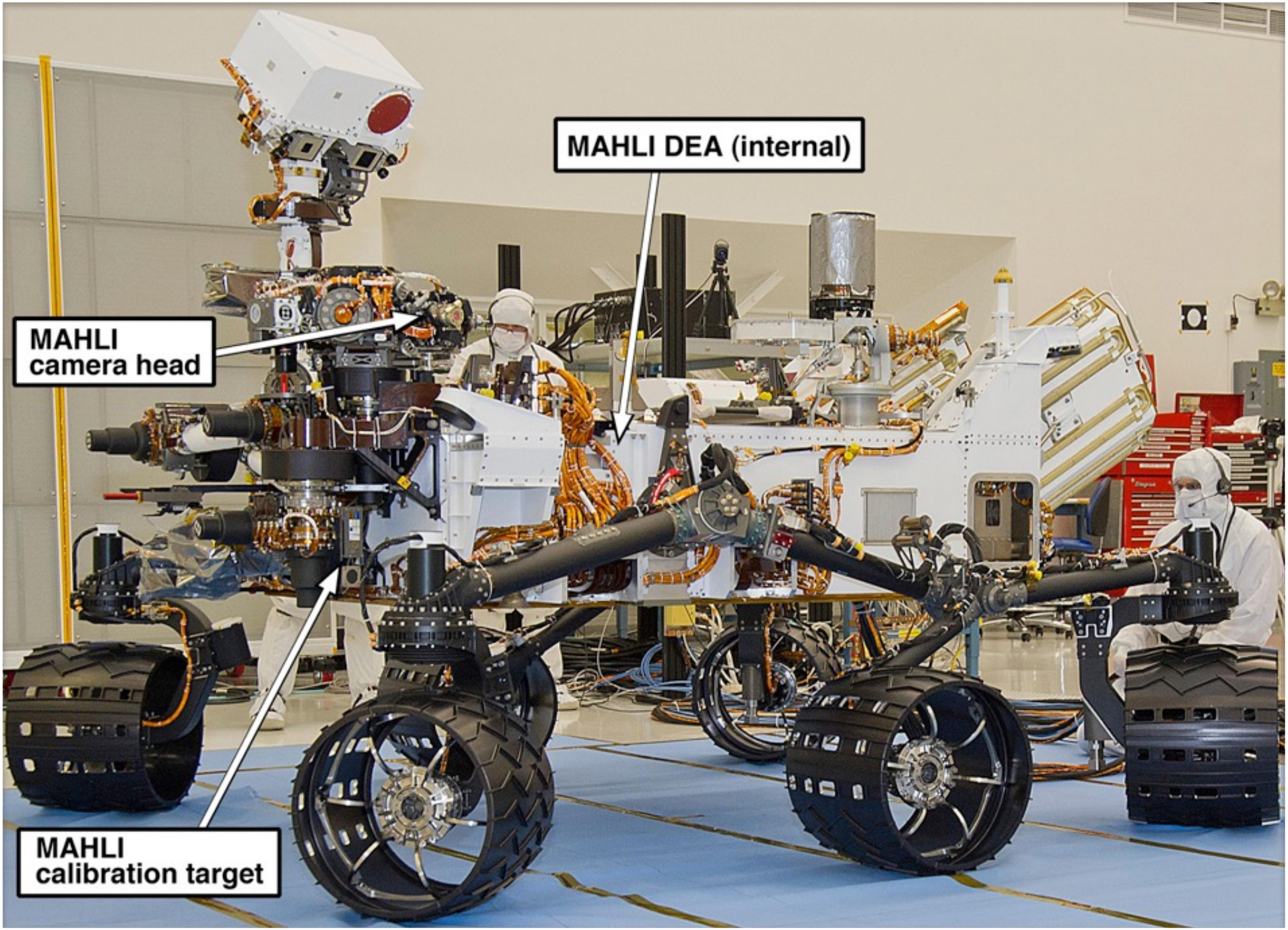
Mars Color Imager

Mars Climate Orbiter & Mars Reconnaissance Orbiter

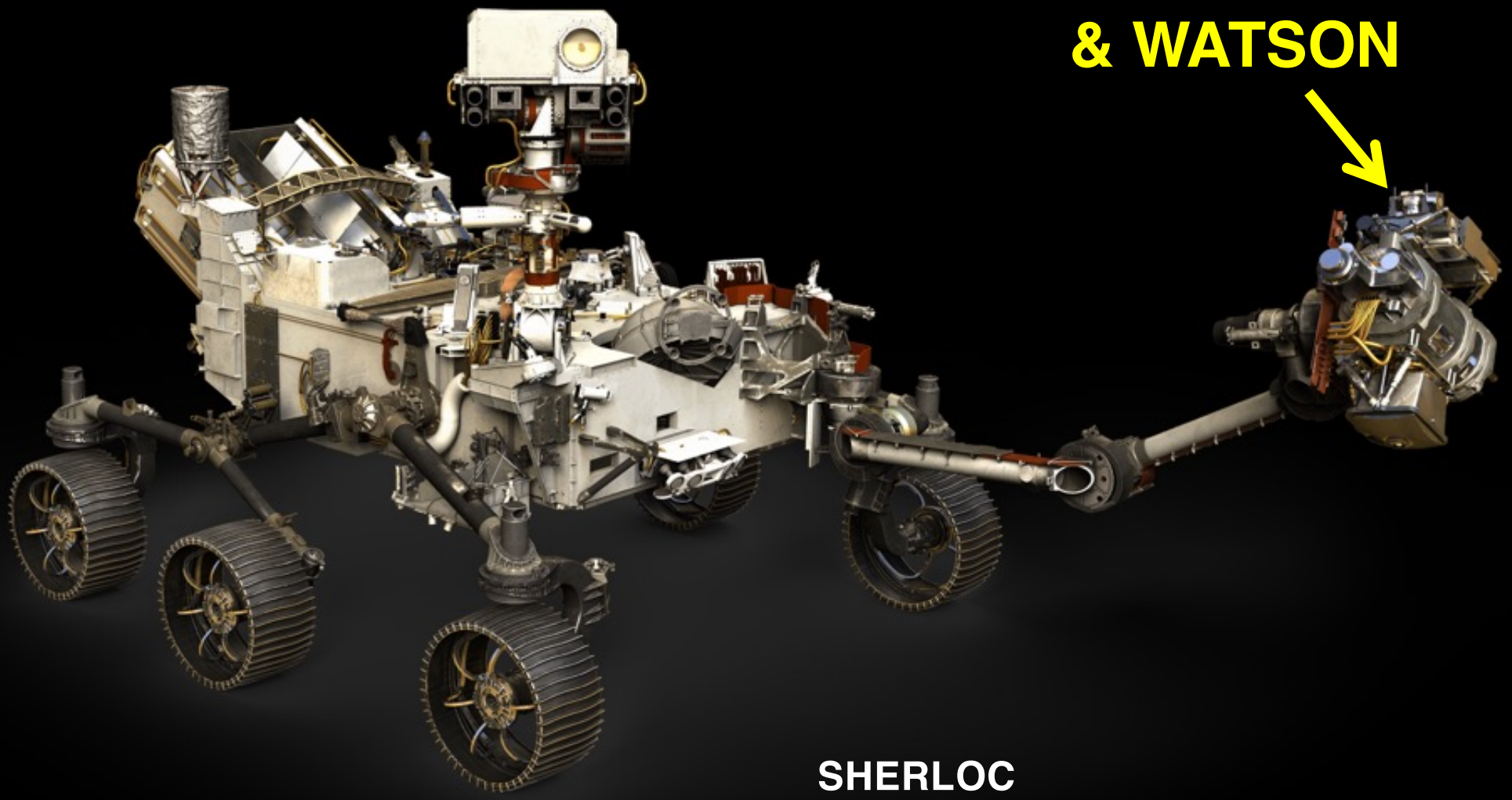
pre-launch testing, 26 August 2008


2 mm


MAHLI
APXS

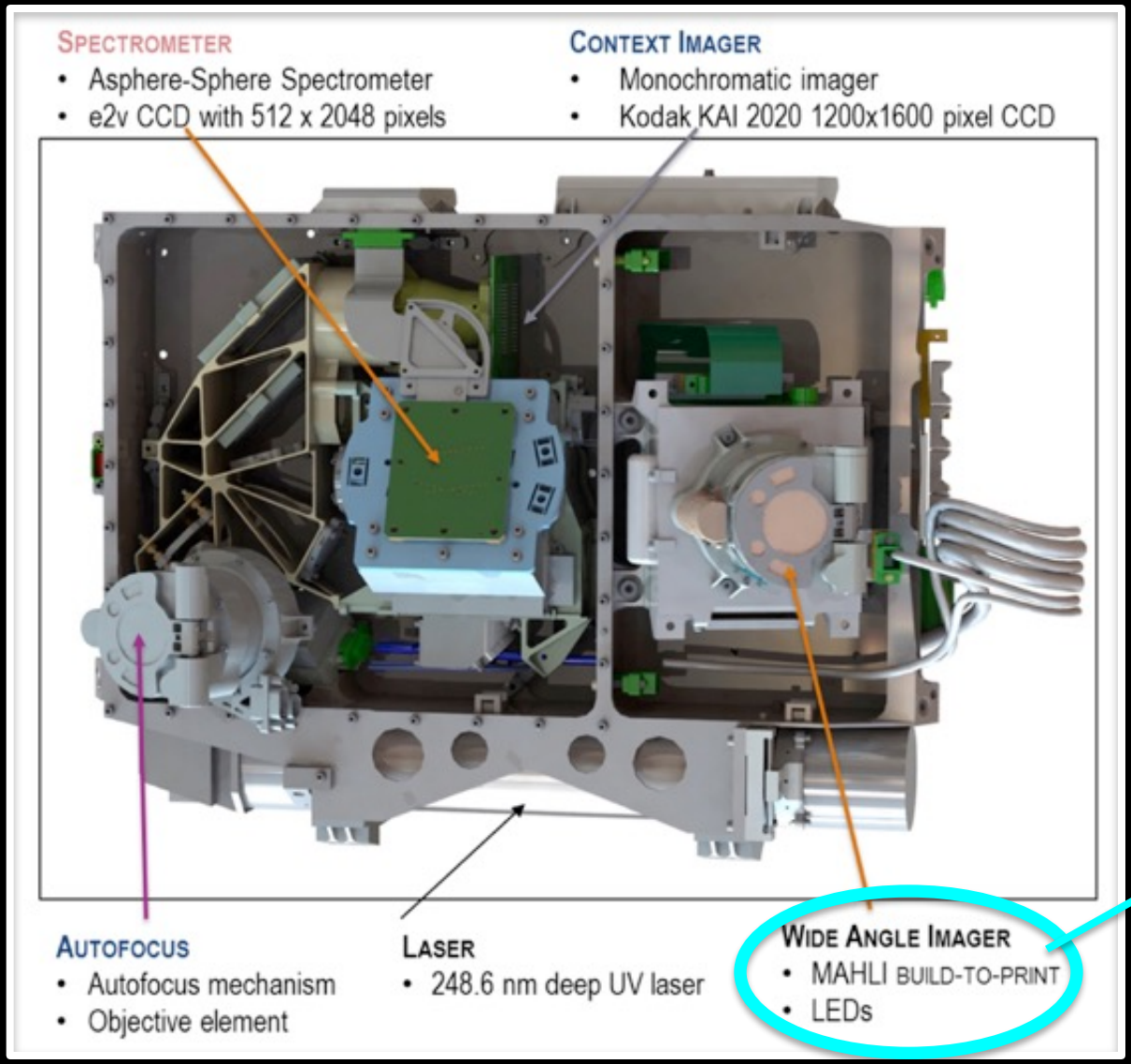

MAHLI DEA (internal)
MAHLI
camera head
MAHLI
calibration target

Mars 2020 Rover



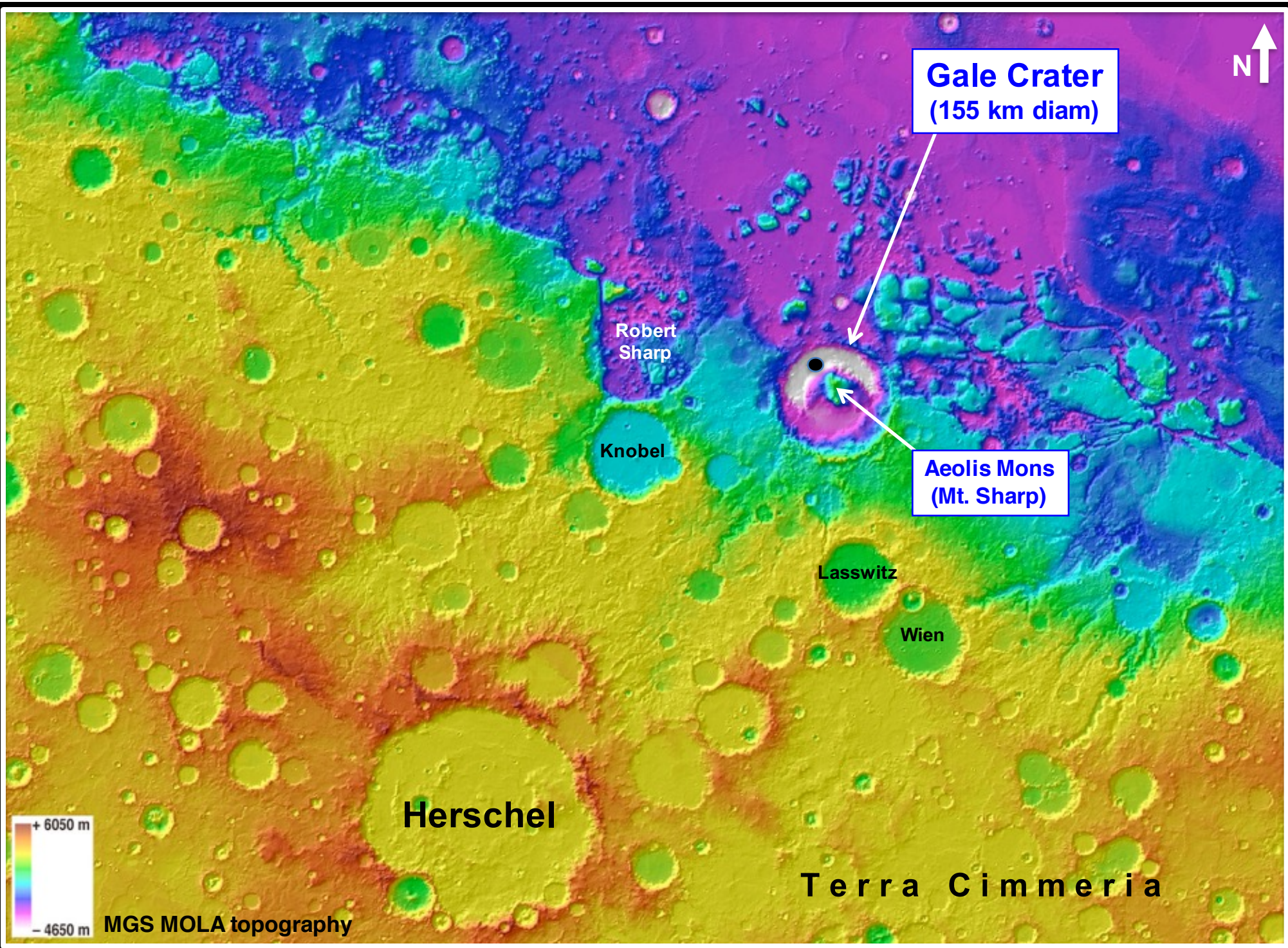
SHERLOC
detects and classifies organics and "astrobiologically relevant" minerals

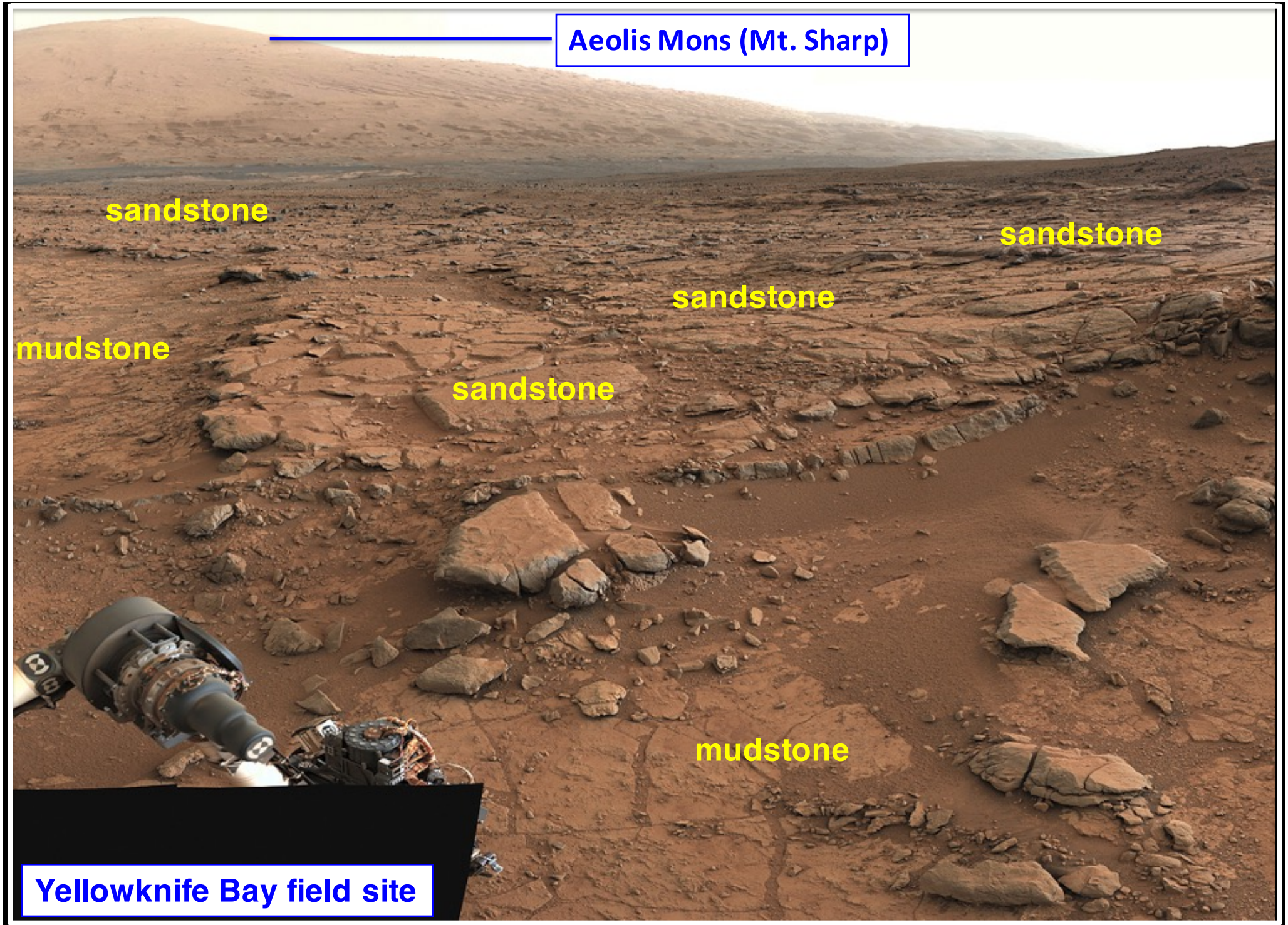
Mars 2020 SHERLOC and WATSON

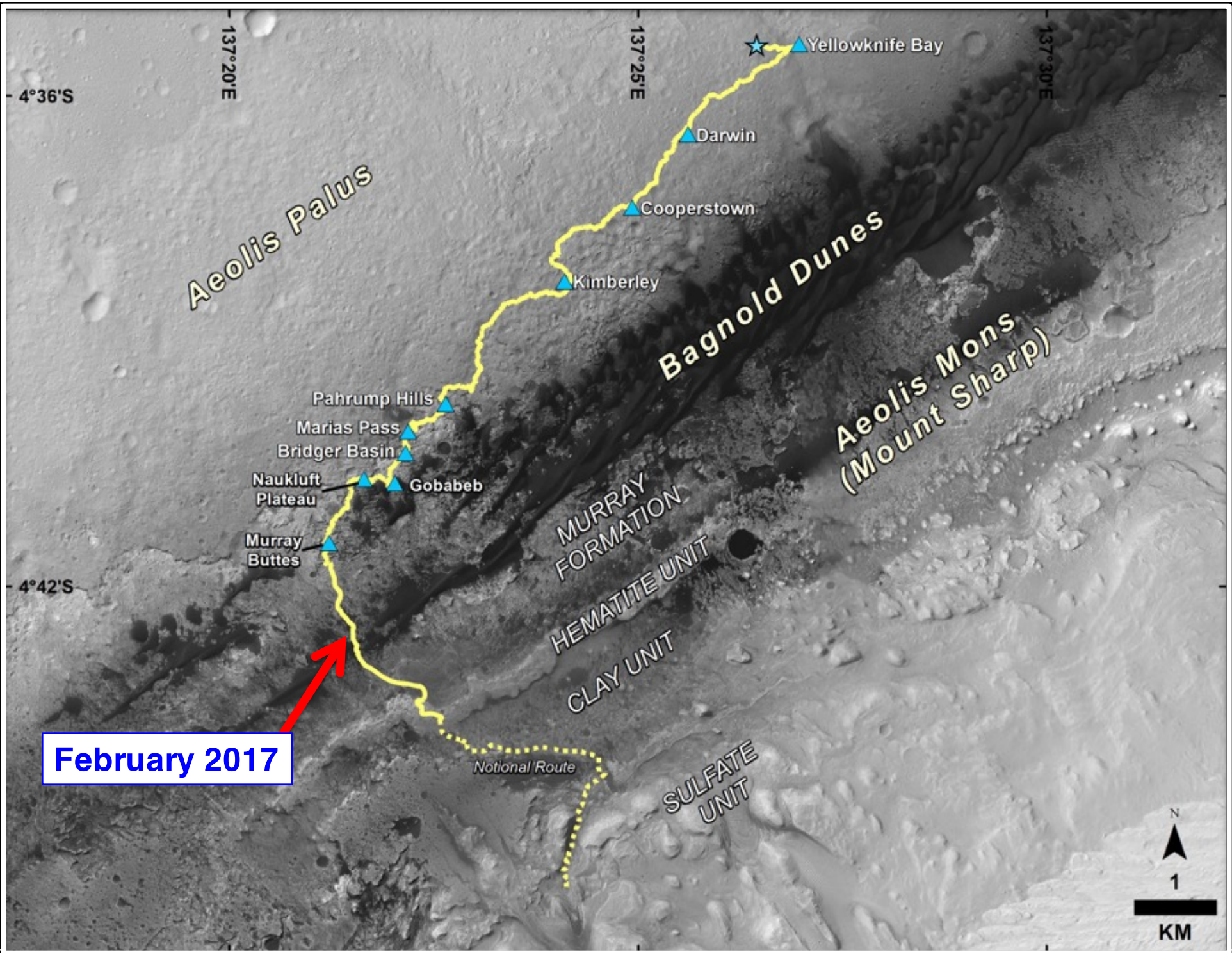


WATSON does what MAHLI does

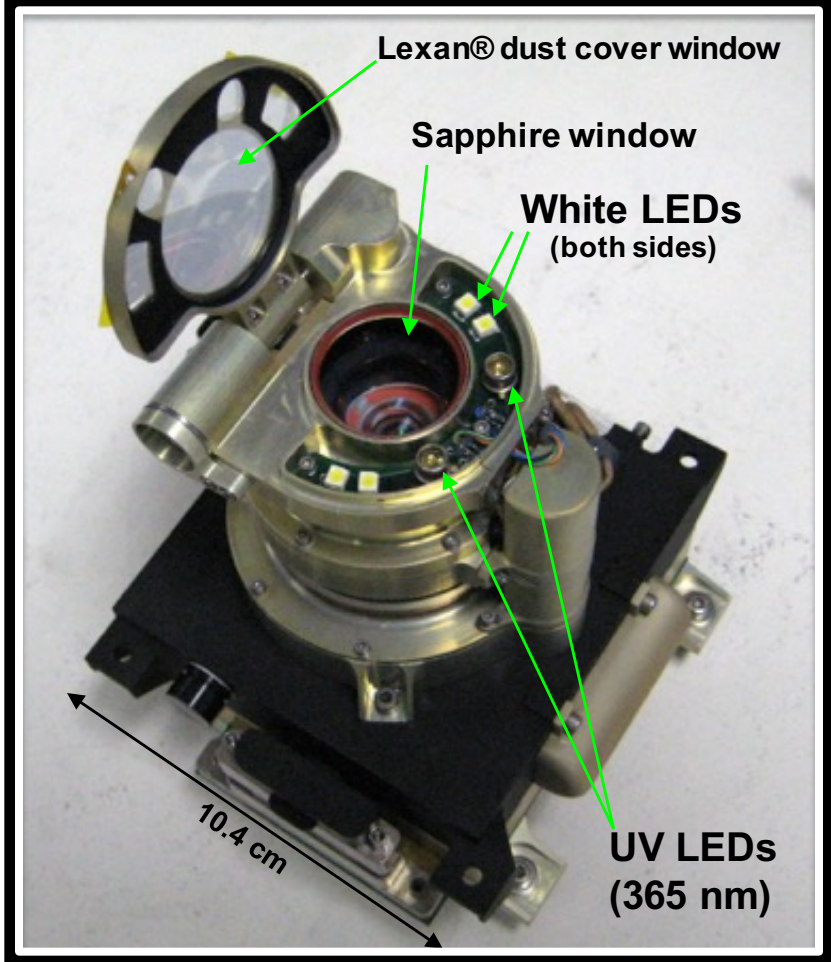
- **SHERLOC – Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals**
- **WATSON – Wide Angle Topographic Sensor for Operations and eNgineering**


Gale Crater
(155 km diam)
N
Robert
Sharp
Knobel
Aeolis Mons
(Mt. Sharp)
Lasswitz
Wien
Herschel
Terra Cimmeria
+ 6050 m
– 4650 m
MGS MOLA topography


Aeolis Mons (Mt. Sharp)
sandstone
sandstone
sandstone
mudstone
sandstone
mudstone
Yellowknife Bay field site

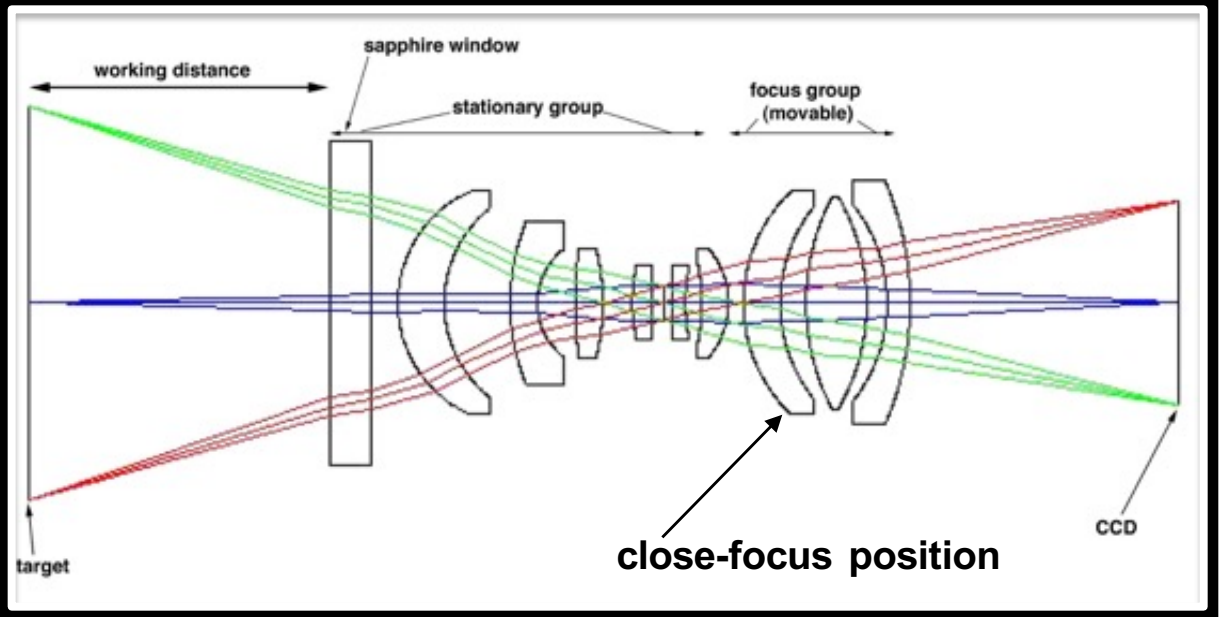

137°20'E
137°25'E
137°30'E
4°36'S
4°42'S
Yellowknife Bay
Darwin
Cooperstown
Kimberley
Pahrump Hills
Marias Pass
Bridger Basin
Naukluft Plateau
Gobabeb
Murray Buttes
Aeolis Palus
Bagnold Dunes
Aeolis Mons (Mount Sharp)
MURRAY FORMATION
HEMATITE UNIT
CLAY UNIT
SULFATE UNIT
Notional Route
February 2017
N
1
KM

MAHLI Camera Head

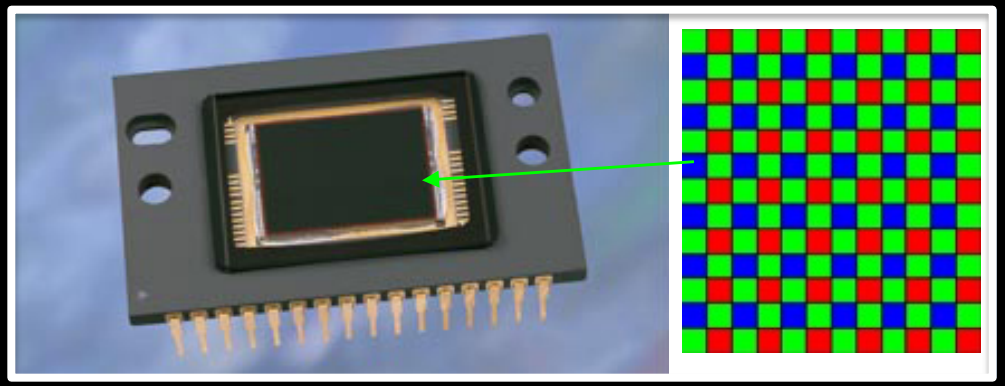


Instrument is typically operated with dust cover fully open. Shown here, it is only half-way open.

FOV = 38.5° diagonal



close: f/9.8, EFL 18.4 mm far: f/8.5, EFL 21.4 mm

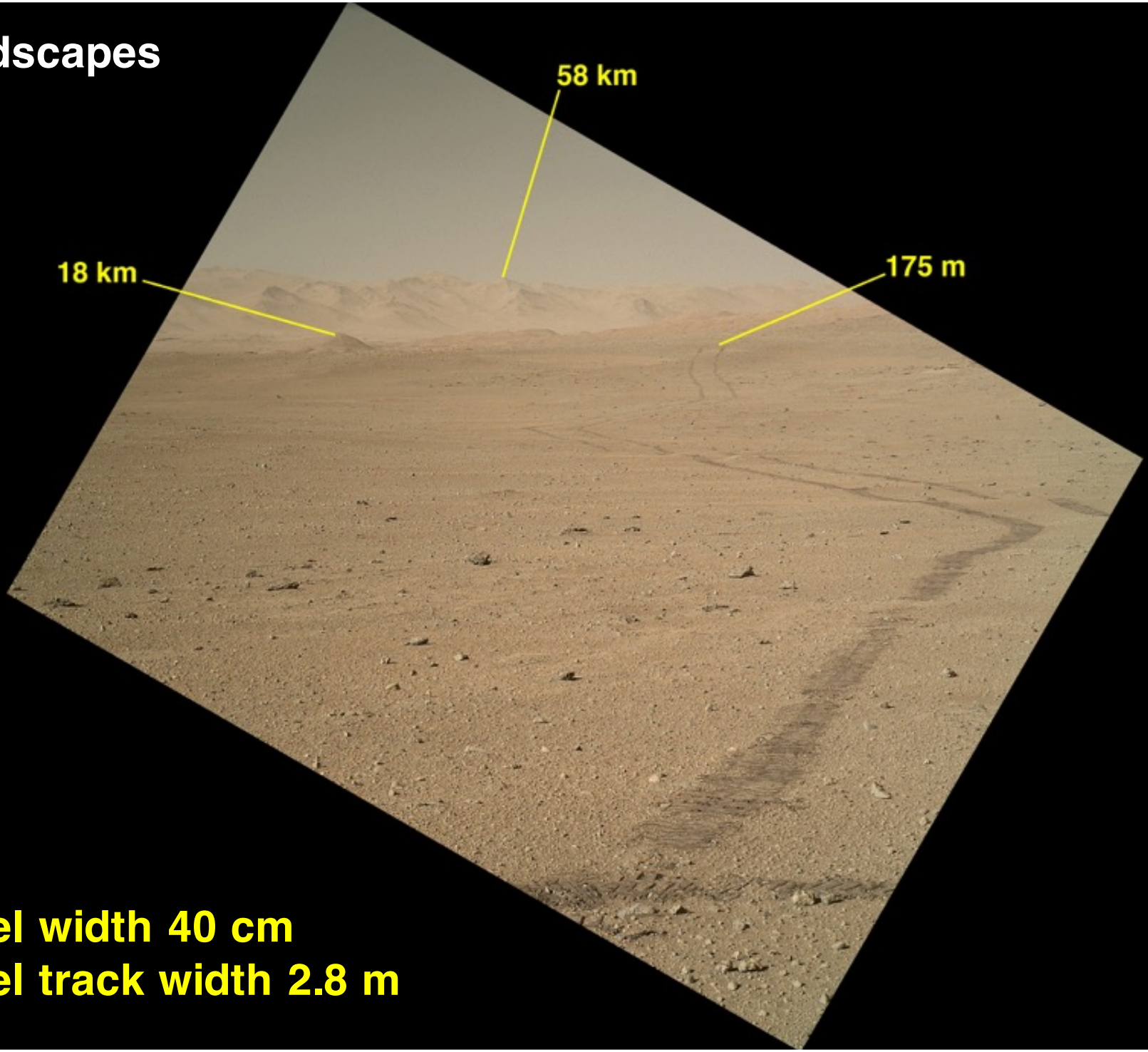


ON Seimiconductor KAI-2020CM CCD
1600 x 1200 7.4 µm pixels

Bayer Pattern microfilters

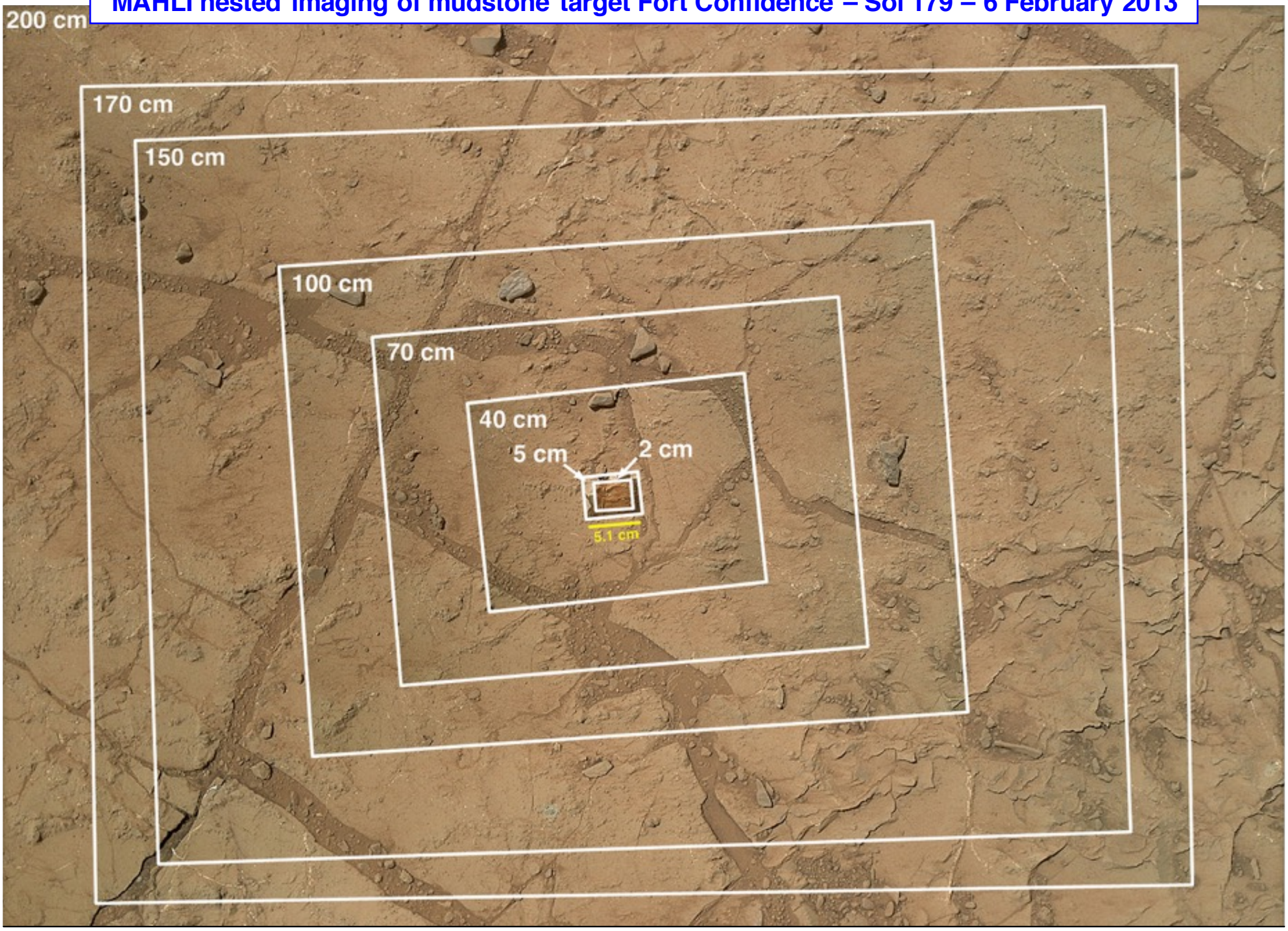
MAHLI 14 *μ*m/pixel view (highest resolution) of Calibration Target Cent – Sol 411 – 2 October 2013

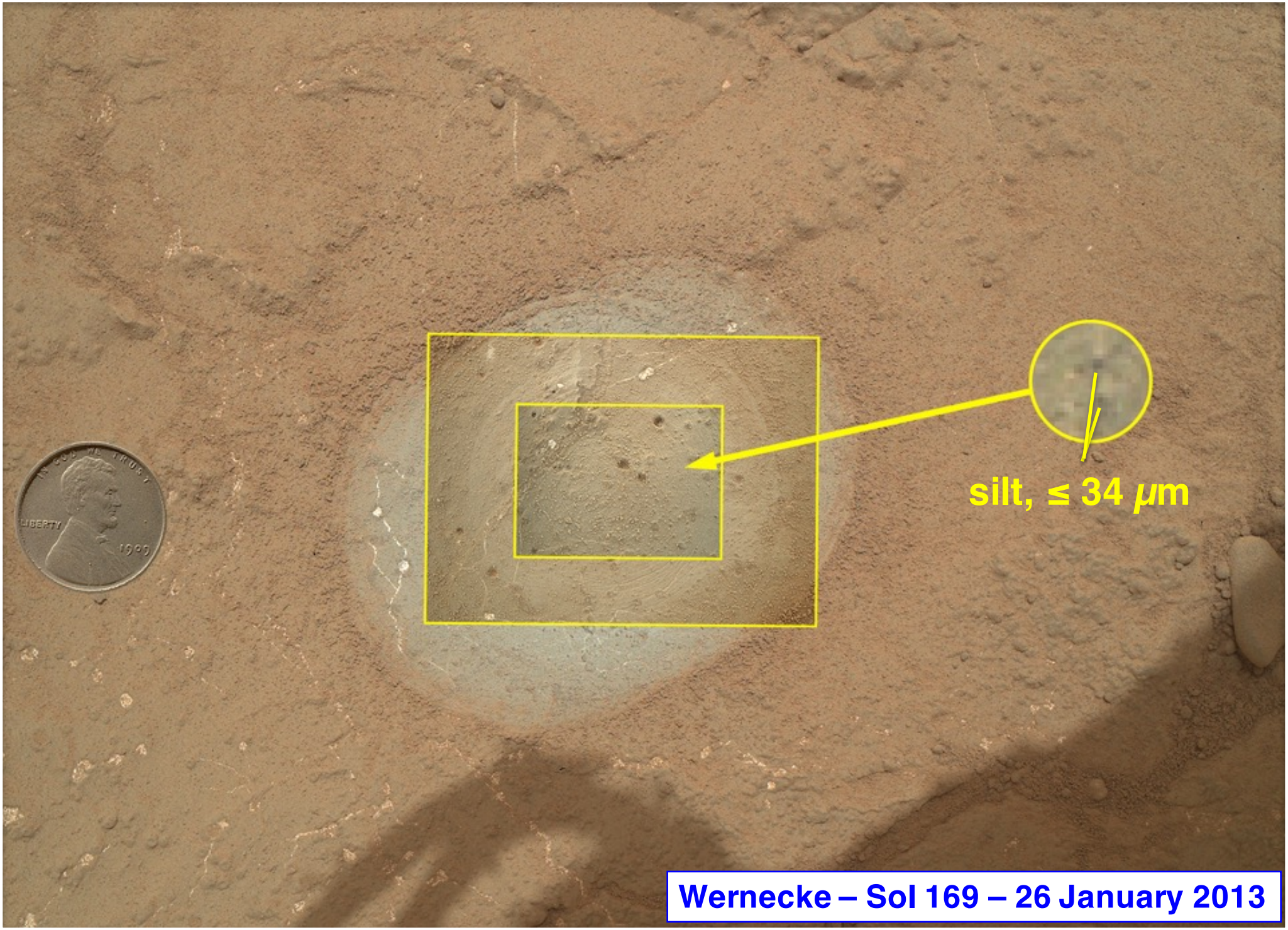
Landscapes

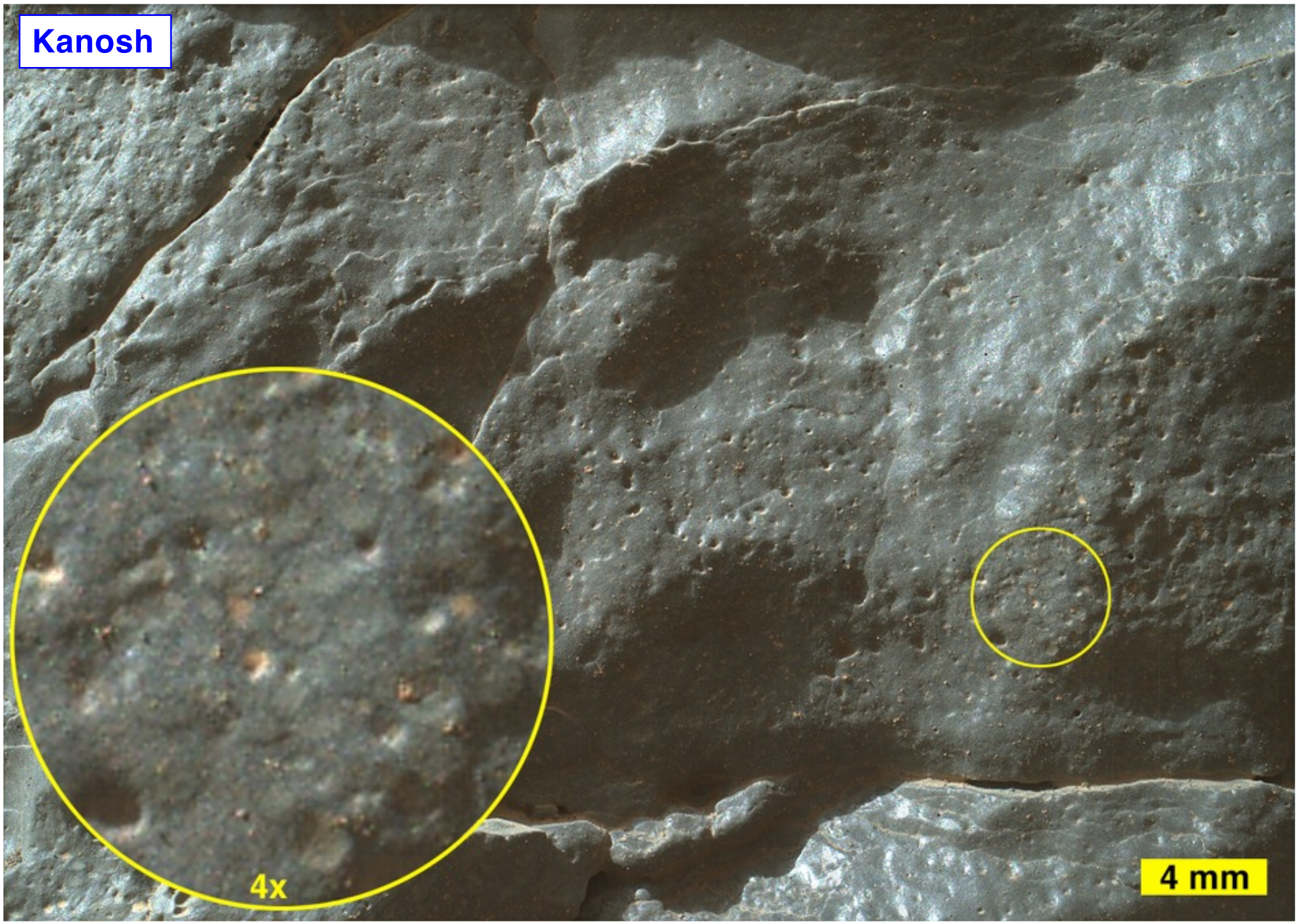


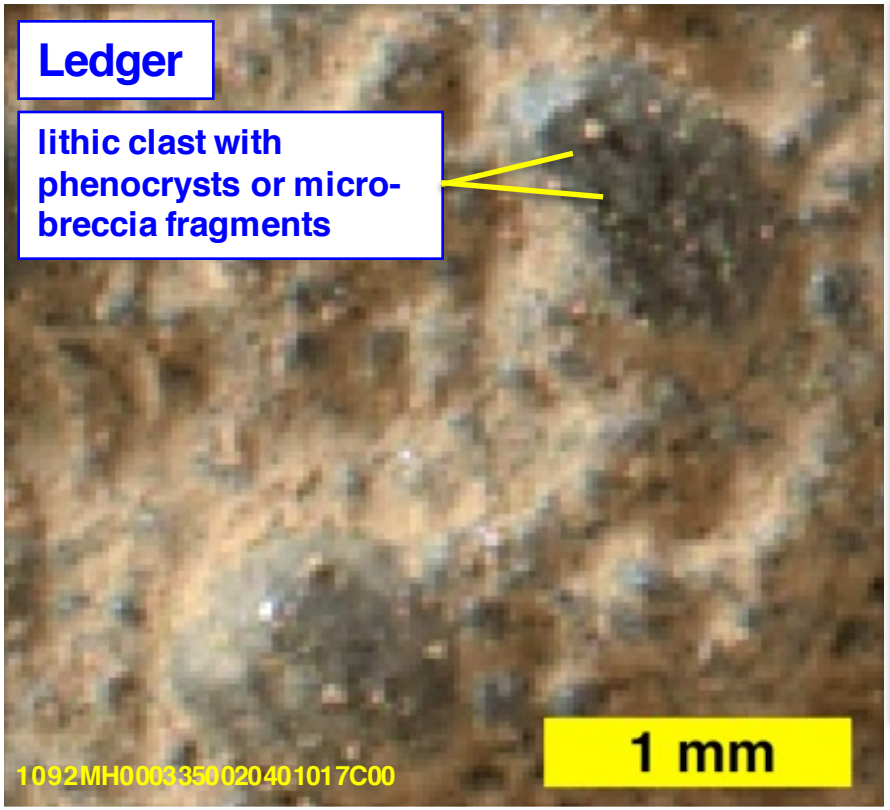
wheel width 40 cm
wheel track width 2.8 m

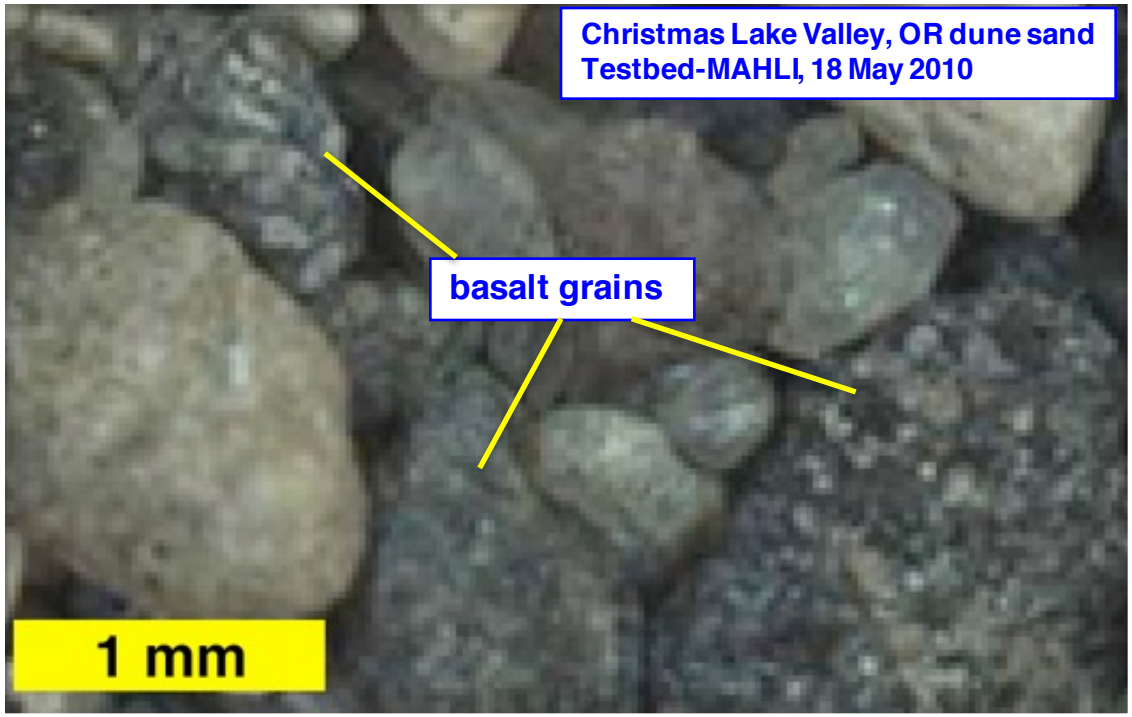
MAHLI nested imaging of mudstone target Fort Confidence – Sol 179 – 6 February 2013

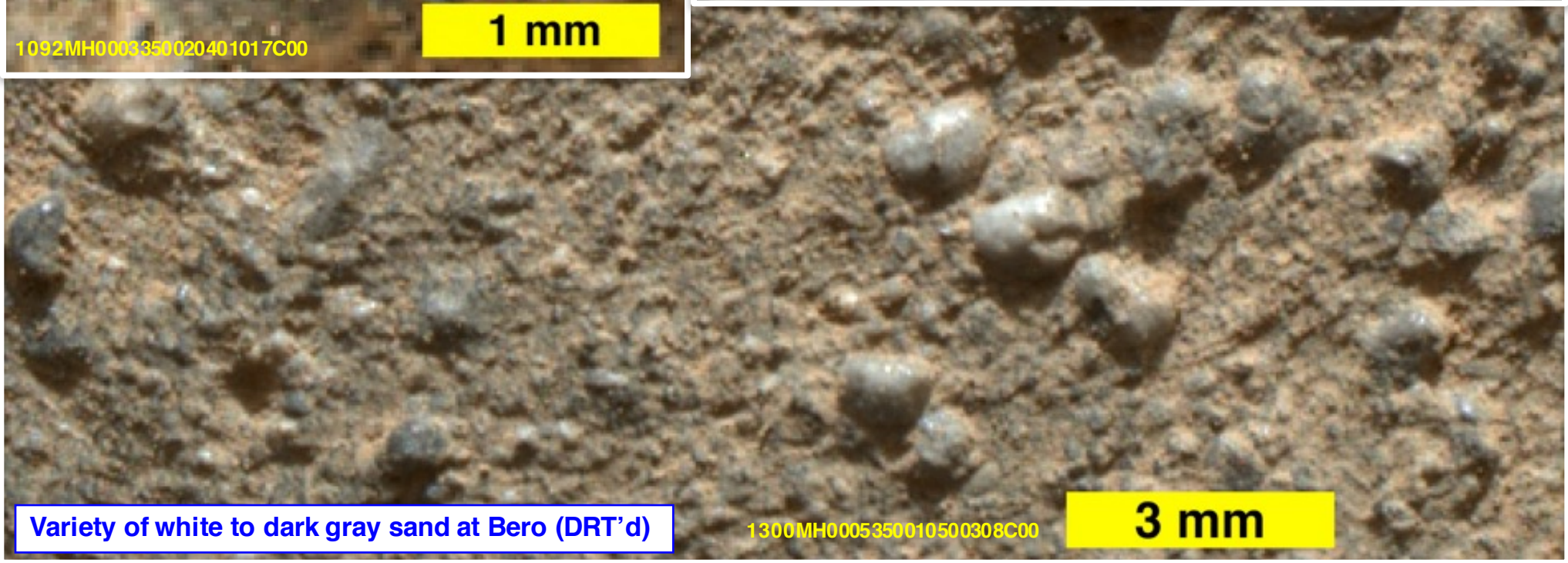


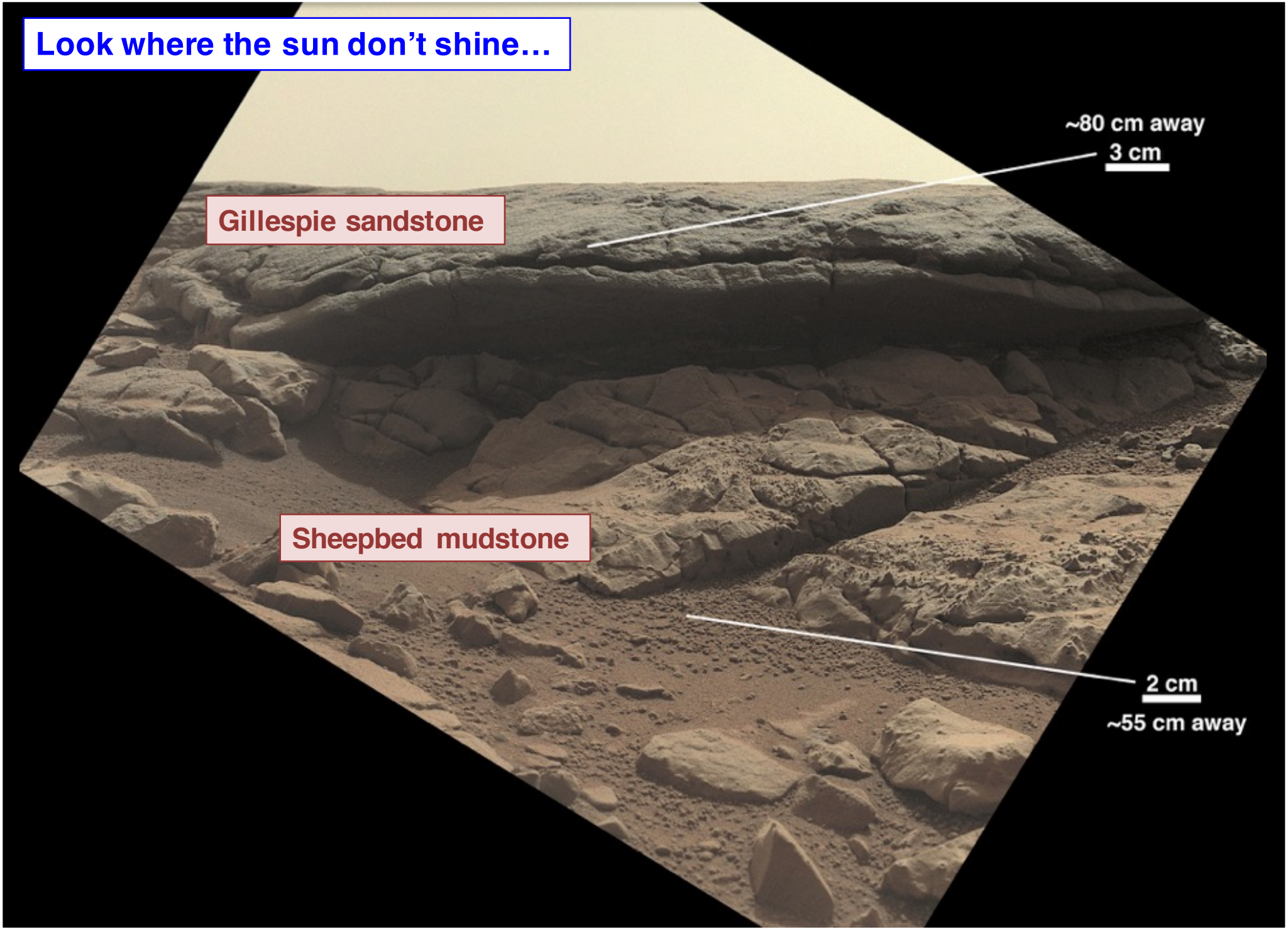

silt, ≤ 34 μm
Wernecke – Sol 169 – 26 January 2013


Kanosh
4x
4 mm

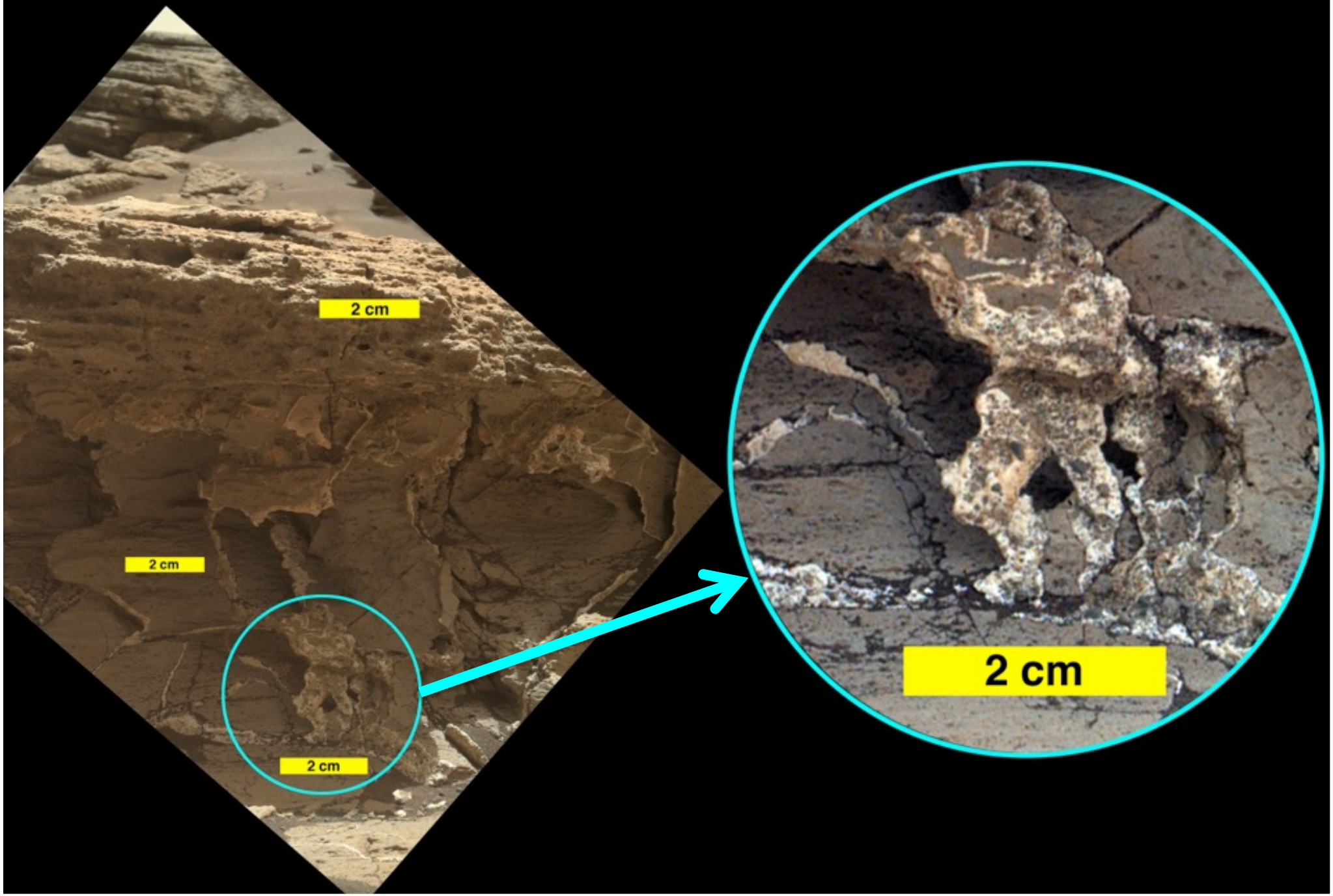

Ledger
lithic clast with phenocrysts or micro-breccia fragments
1 mm
1092MH0003350020401017C00


Christmas Lake Valley, OR dune sand
Testbed-MAHLI, 18 May 2010
basalt grains
1 mm

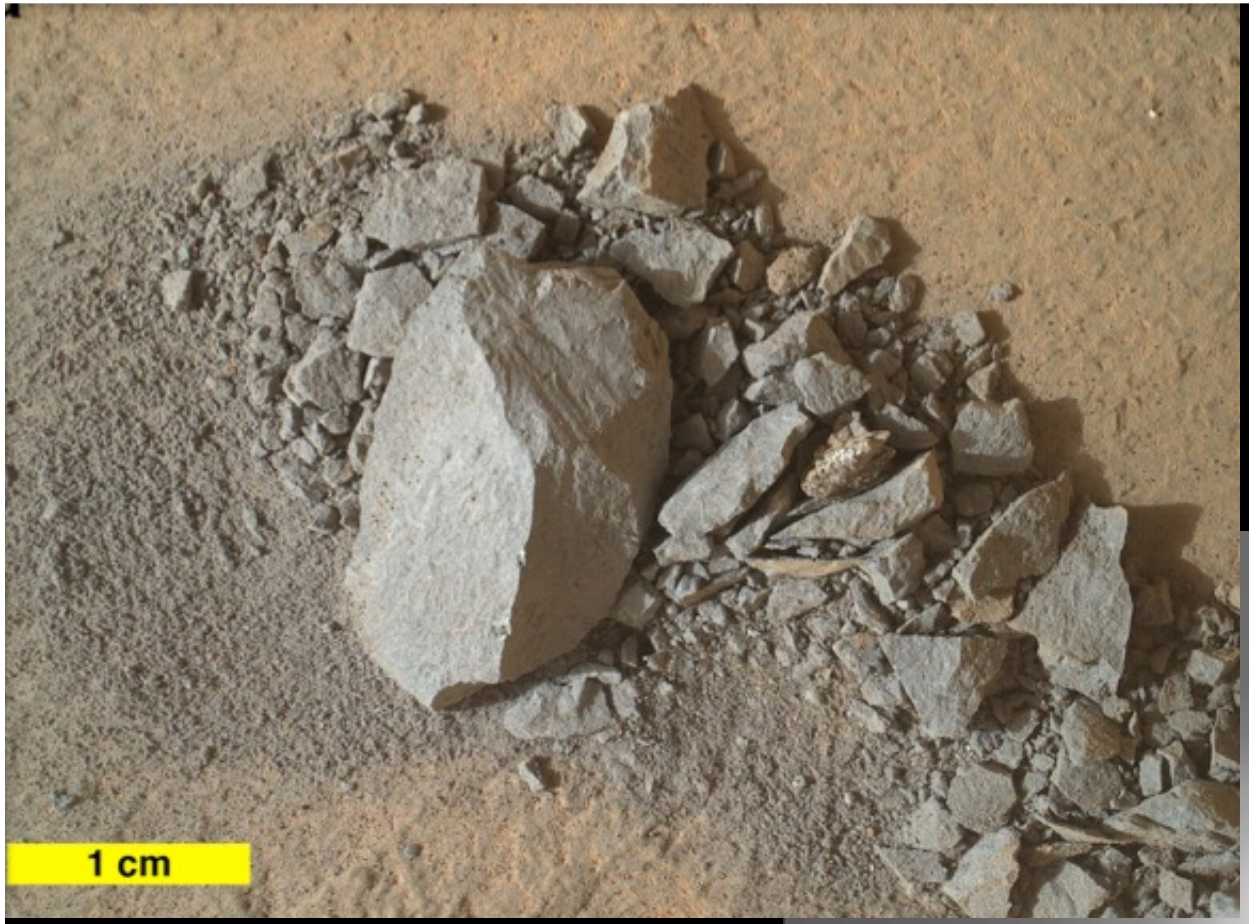

Variety of white to dark gray sand at Bero (DRT'd)
1300MH0005350010500308C00
3 mm


Look where the sun don't shine…
~80 cm away
3 cm
Gillespie sandstone
Sheepbed mudstone
2 cm
~55 cm away

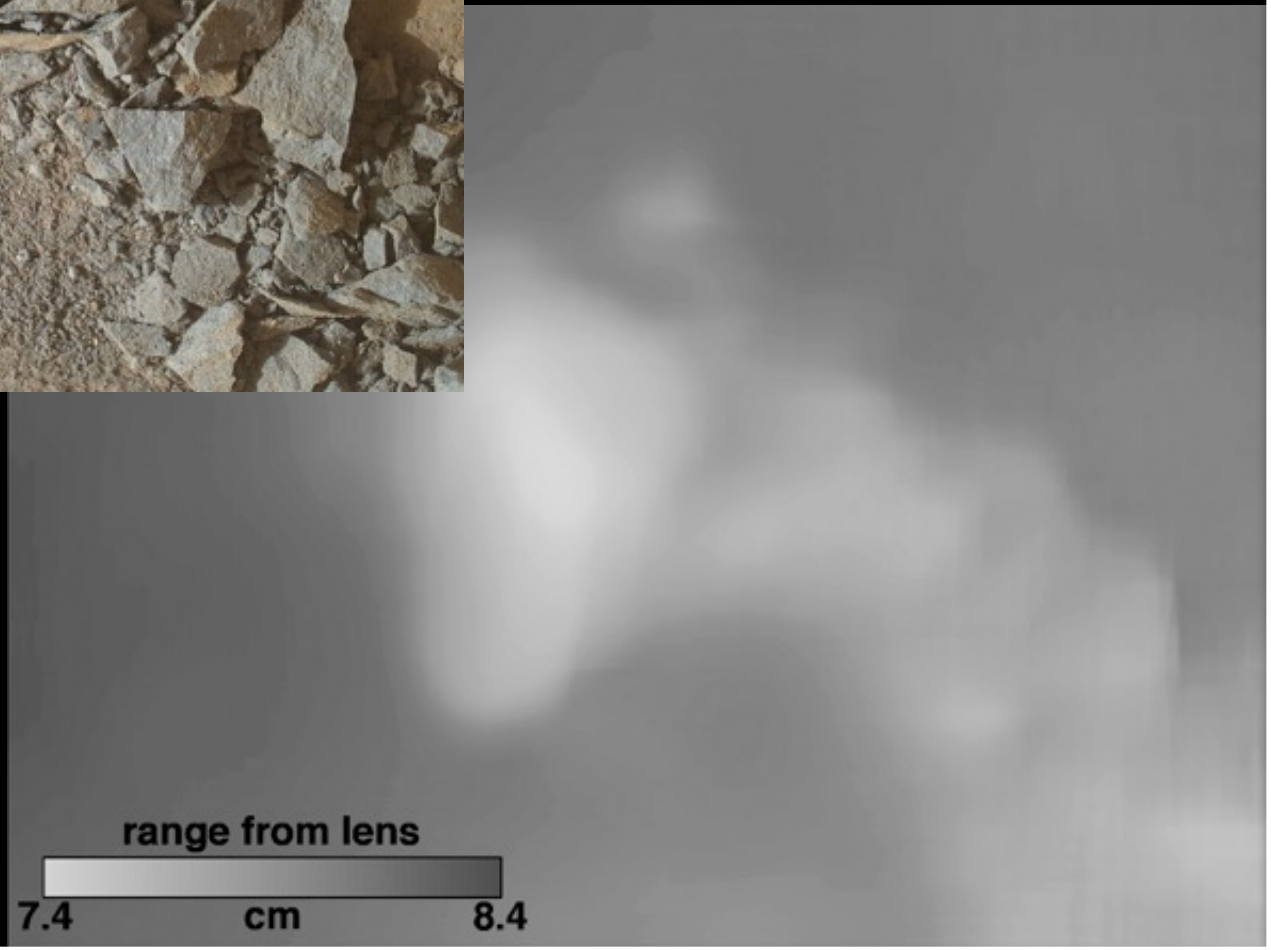
Mudstone beneath sandstone overhang at Missoula outcrop, Sol 1031



Onboard focus stack merge capability



0869MH0004610000302276R00



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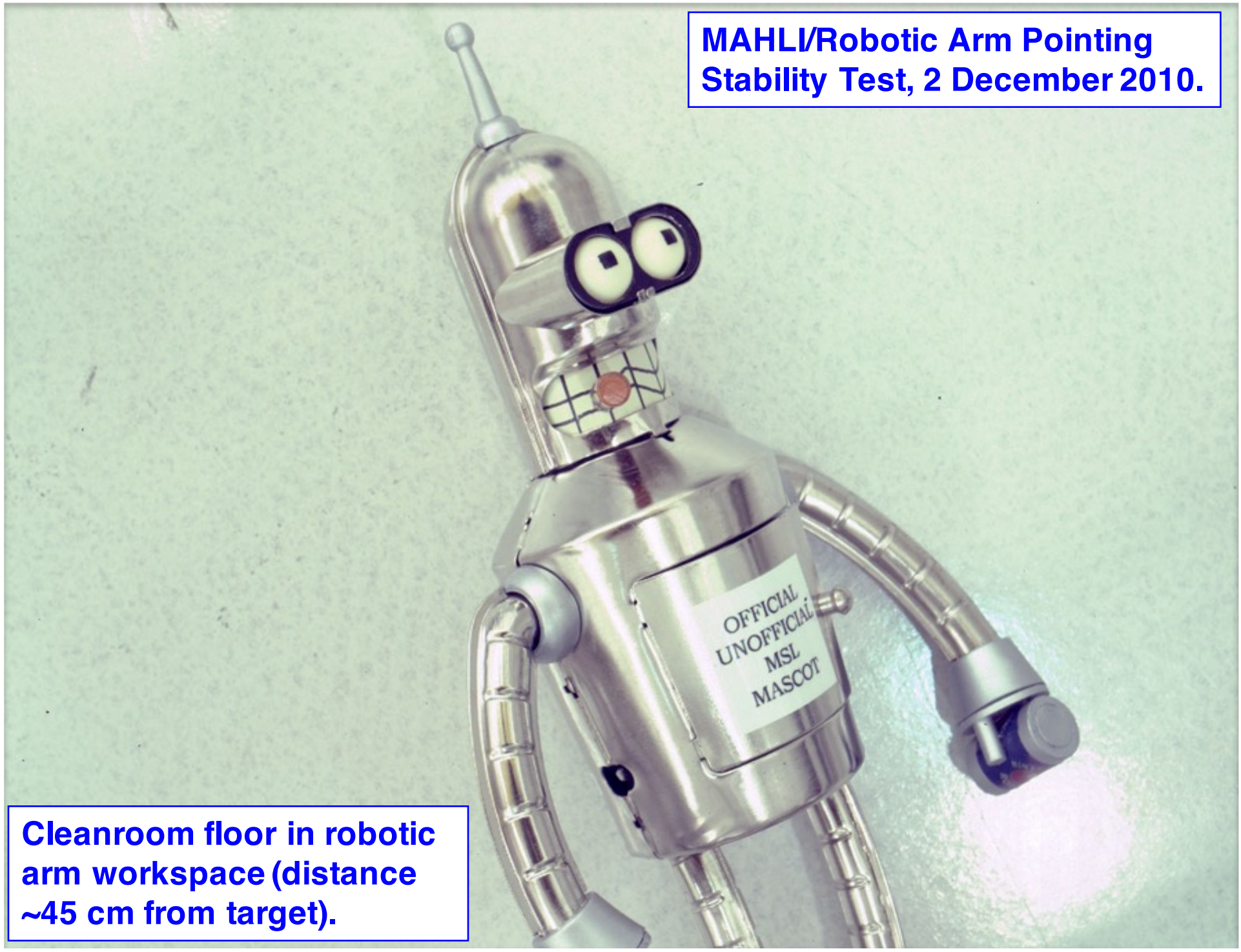
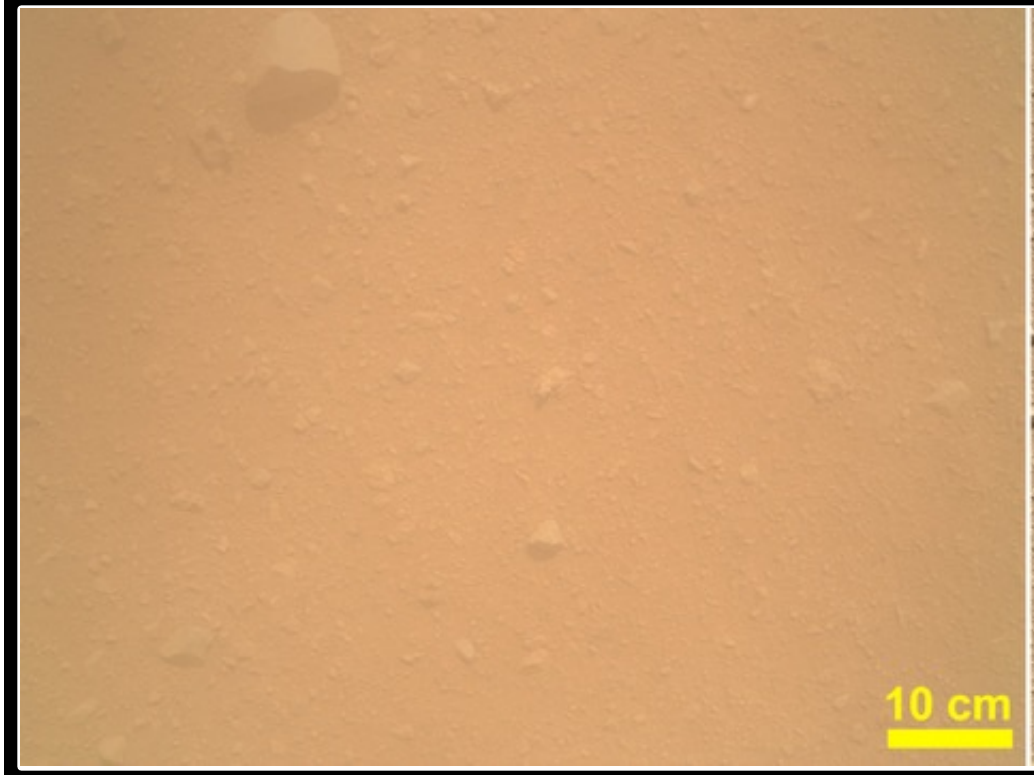


MAHLI/Robotic Arm Pointing Stability Test, 2 December 2010.

Cleanroom floor in robotic arm workspace (distance ~45 cm from target).

MAHLI First Opening of Dust Cover – Instrument Check-Out
Sol 33 – 9 September 2012



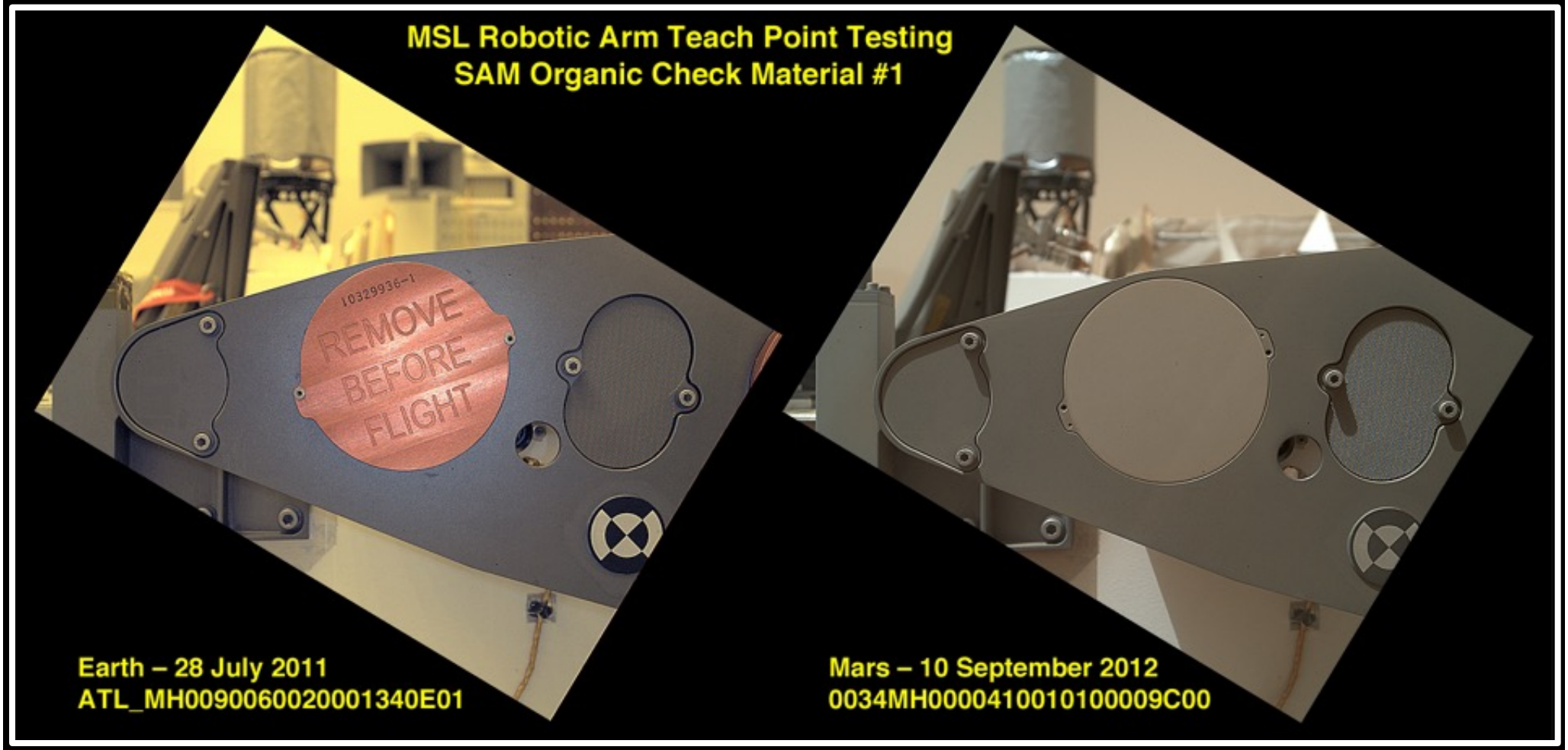
dust cover closed

Transparent cover was coated with a thin film of dust during rover's terminal descent.

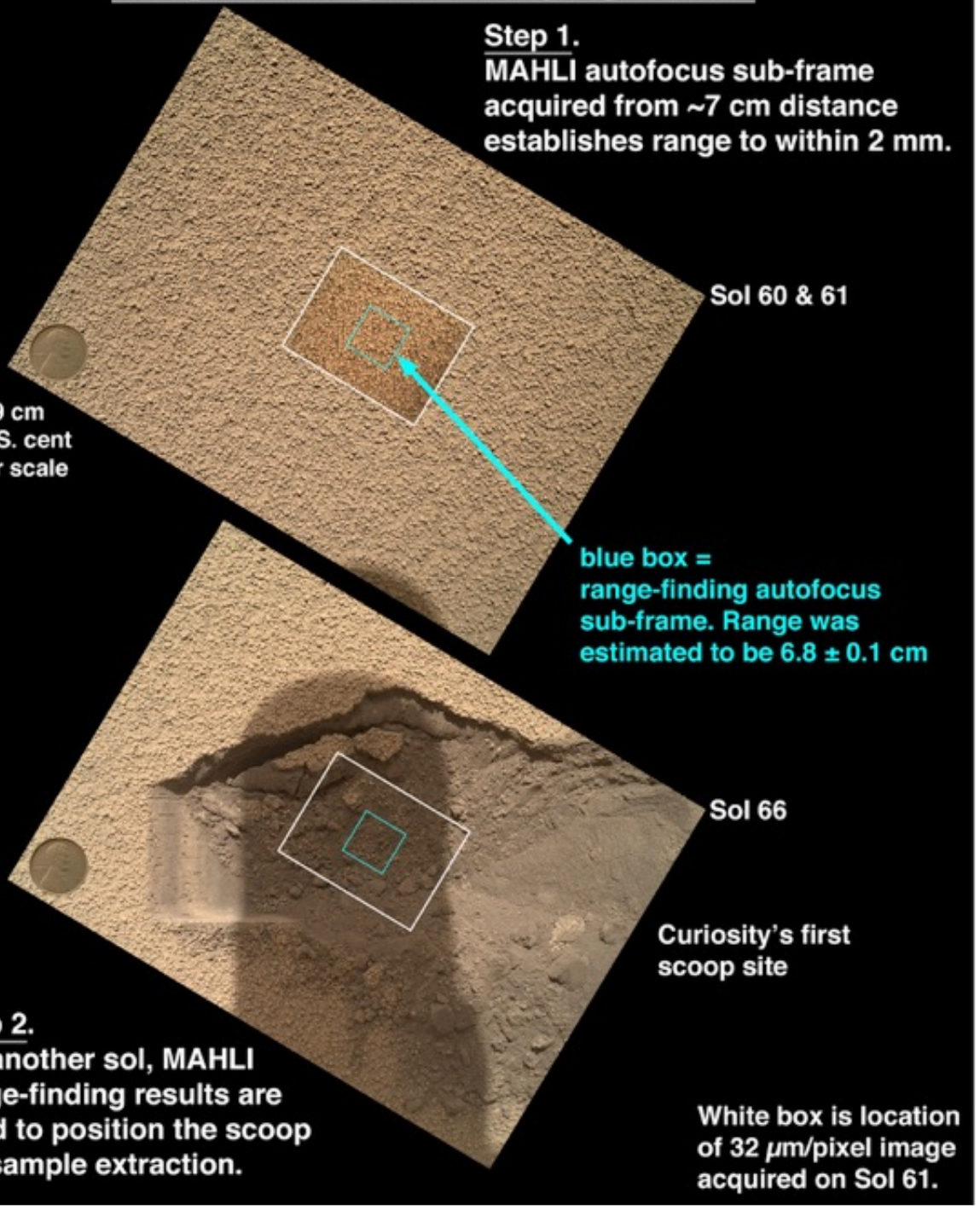
dust cover open

Front lens element was clean; protected by dust cover during rover's terminal descent.

Robotic Arm Commissioning & Operation Support

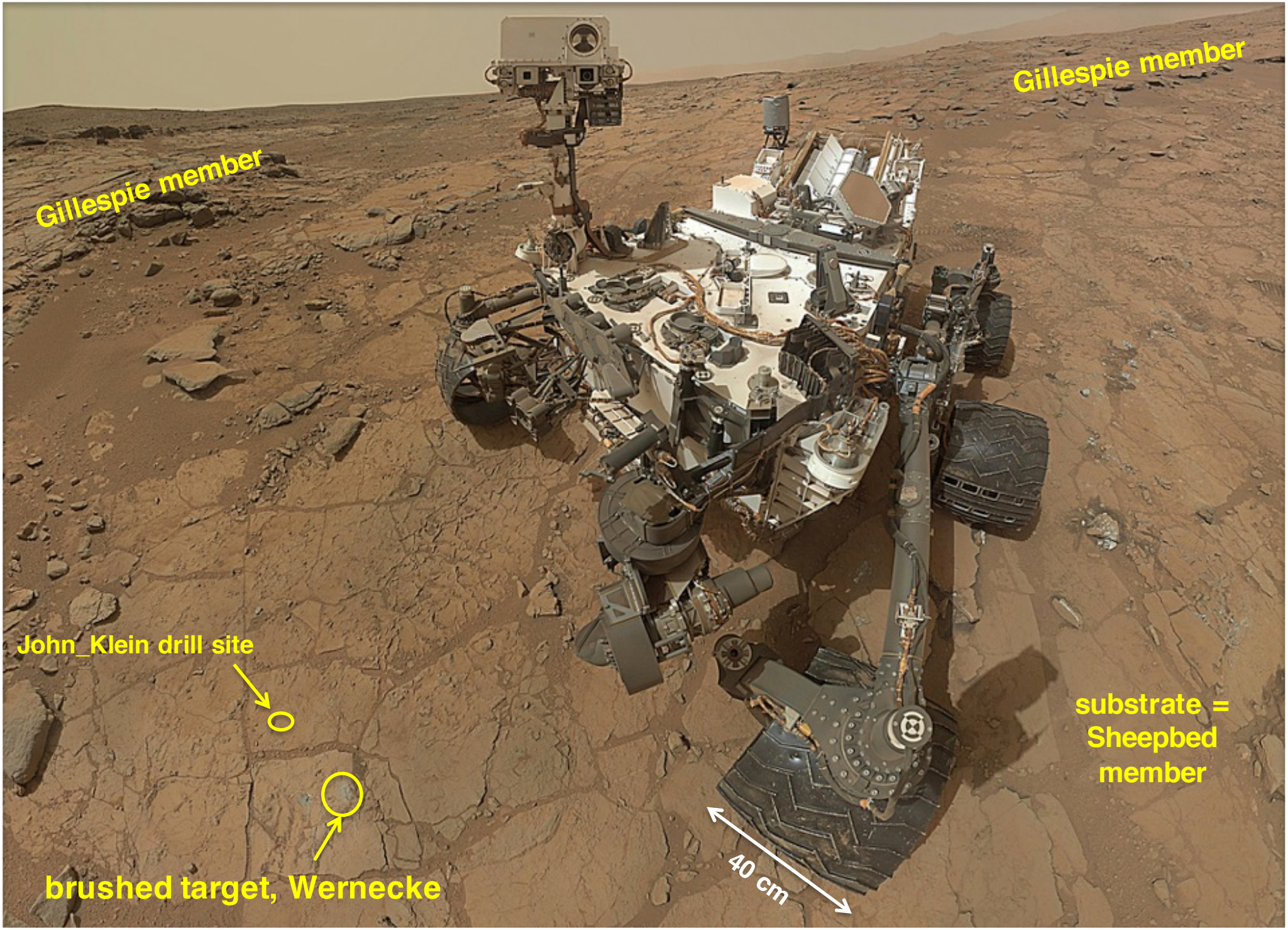


Range-Finding for Scooping Efforts

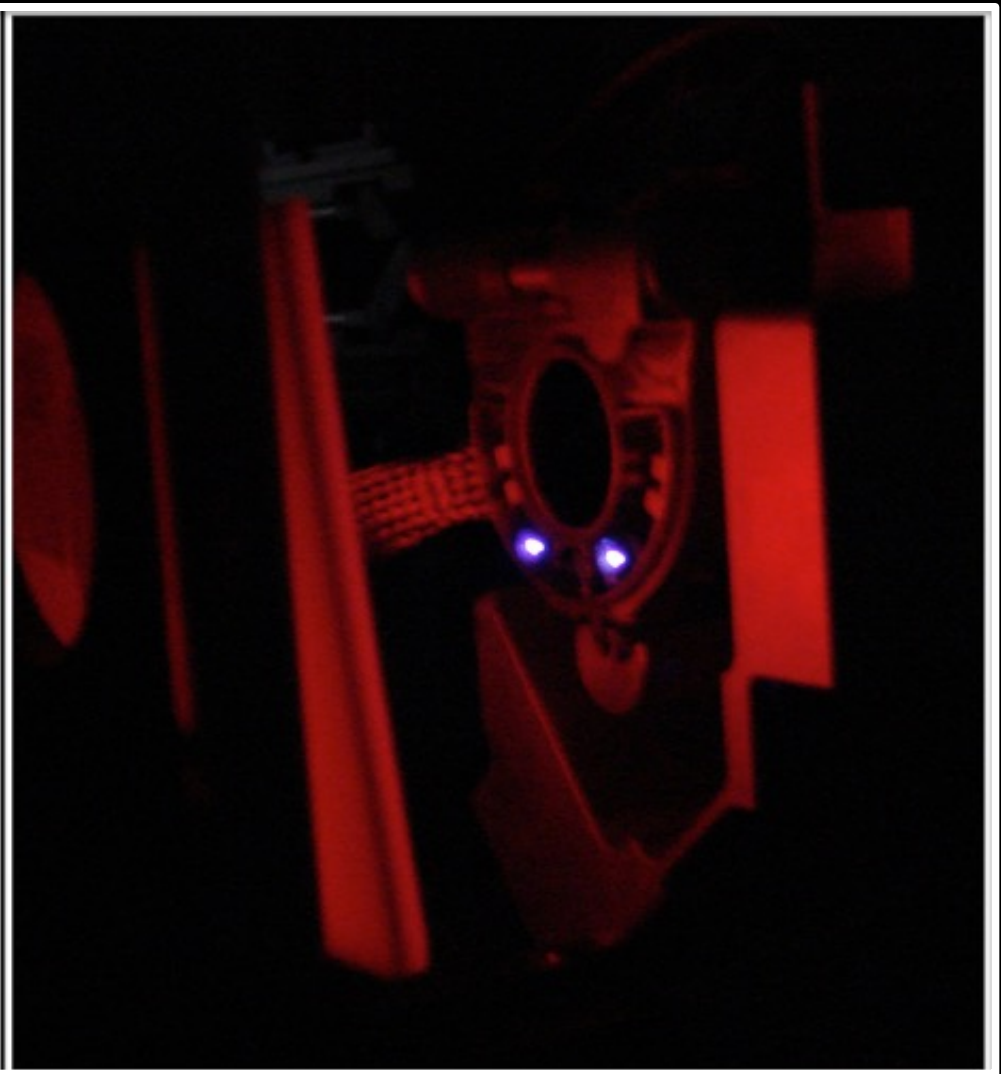


John Klein drill hole – Sol 270 – 10 May 2013

16 mm diameter


Gillespie member
Gillespie member
John_Klein drill site
brushed target, Wernecke
40 cm
substrate = Sheepbed member

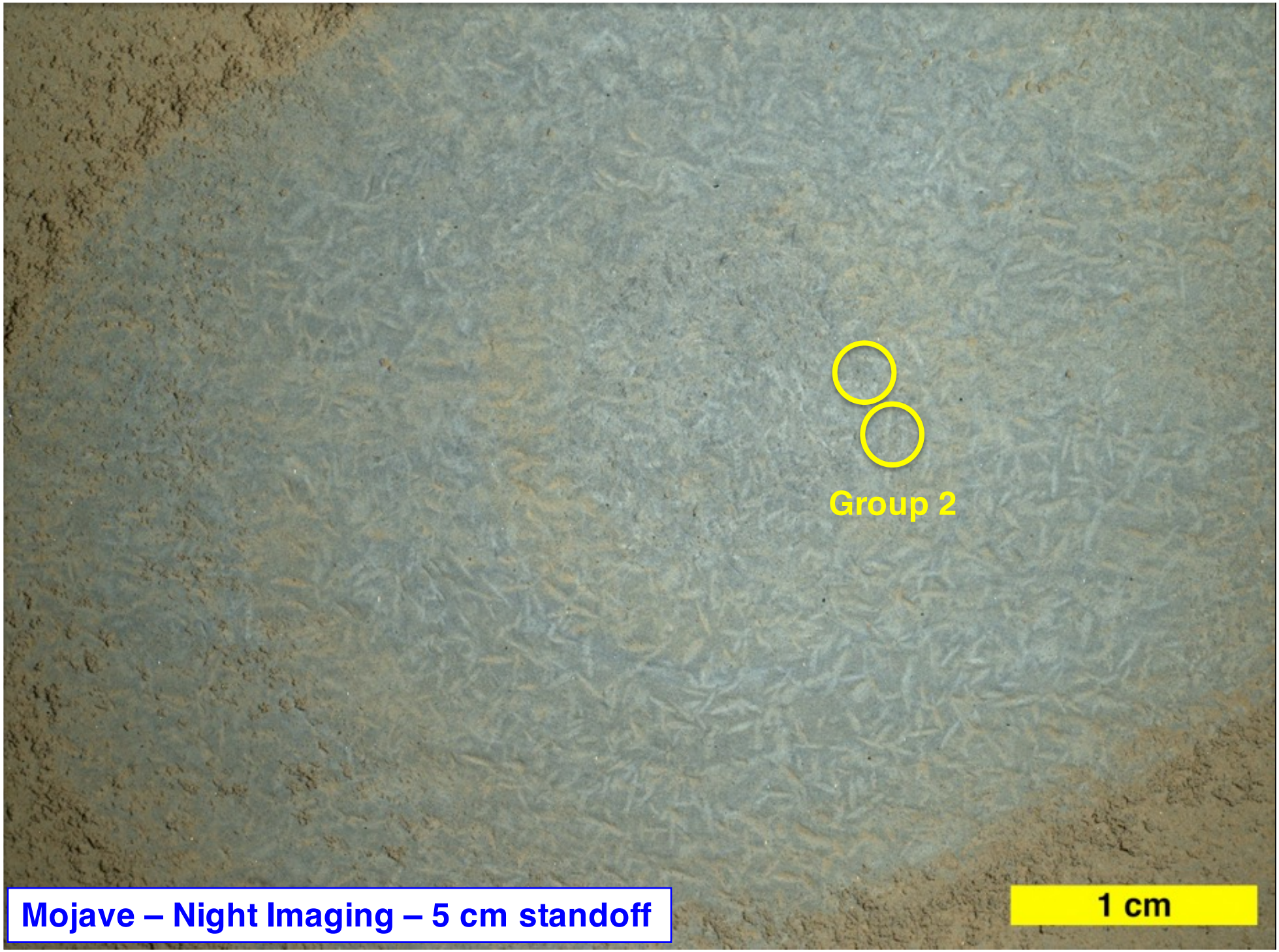
MAHLI LEDs



4 White Light LEDs
Can control each group of 2 separately

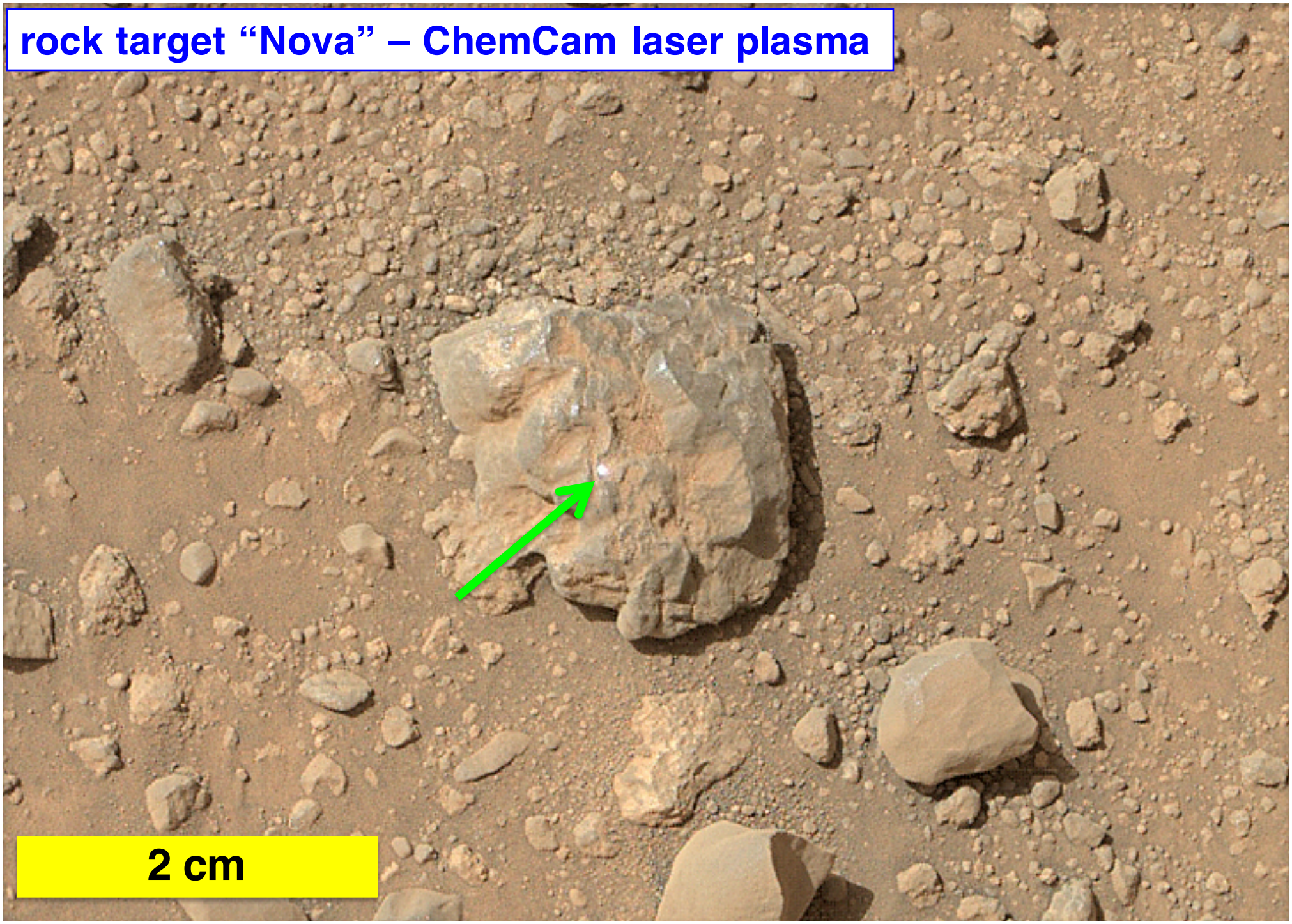
2 UV LEDs (365 nm)
To seek fluorescent materials

Mojave – Night Imaging – 5 cm standoff

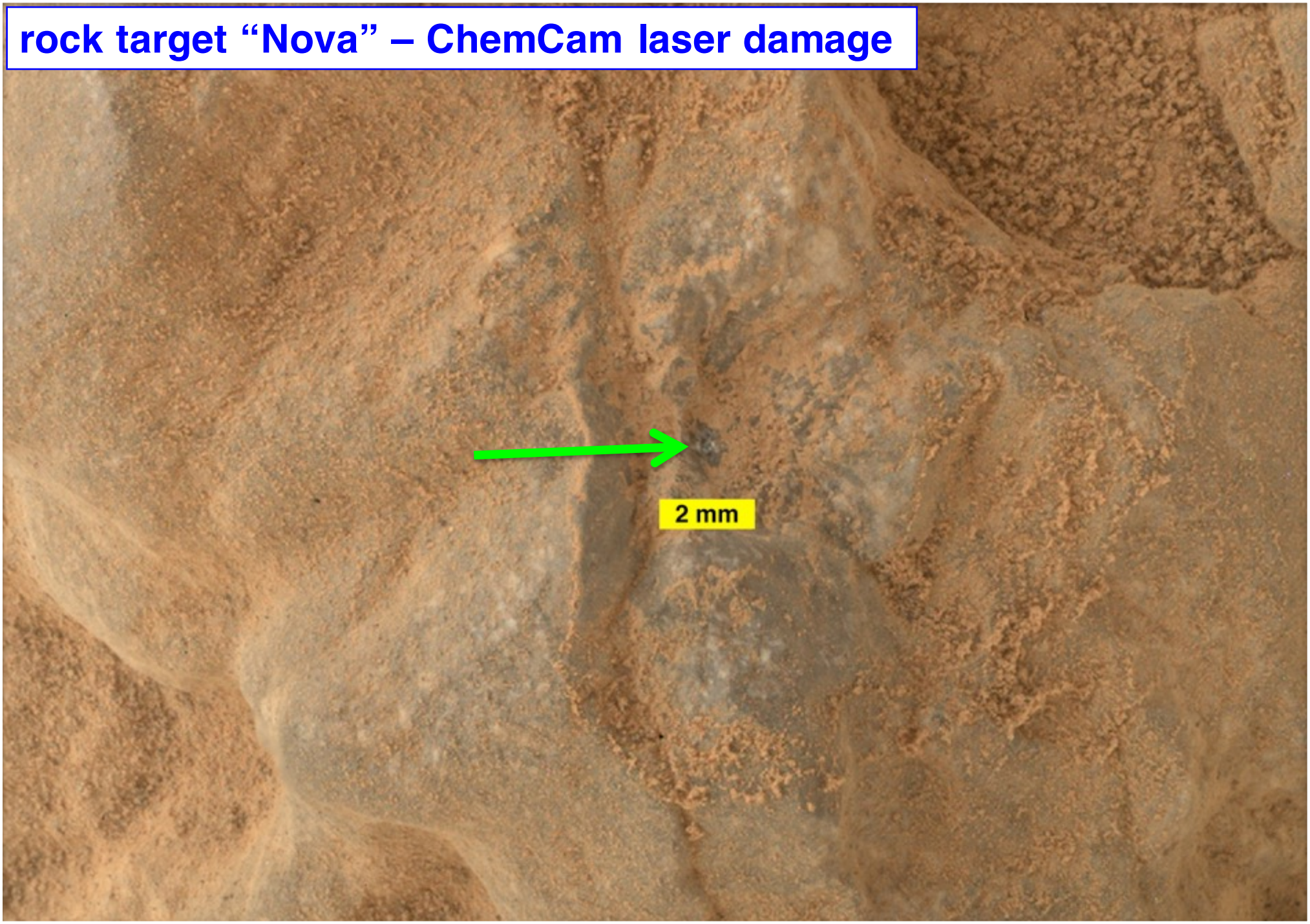


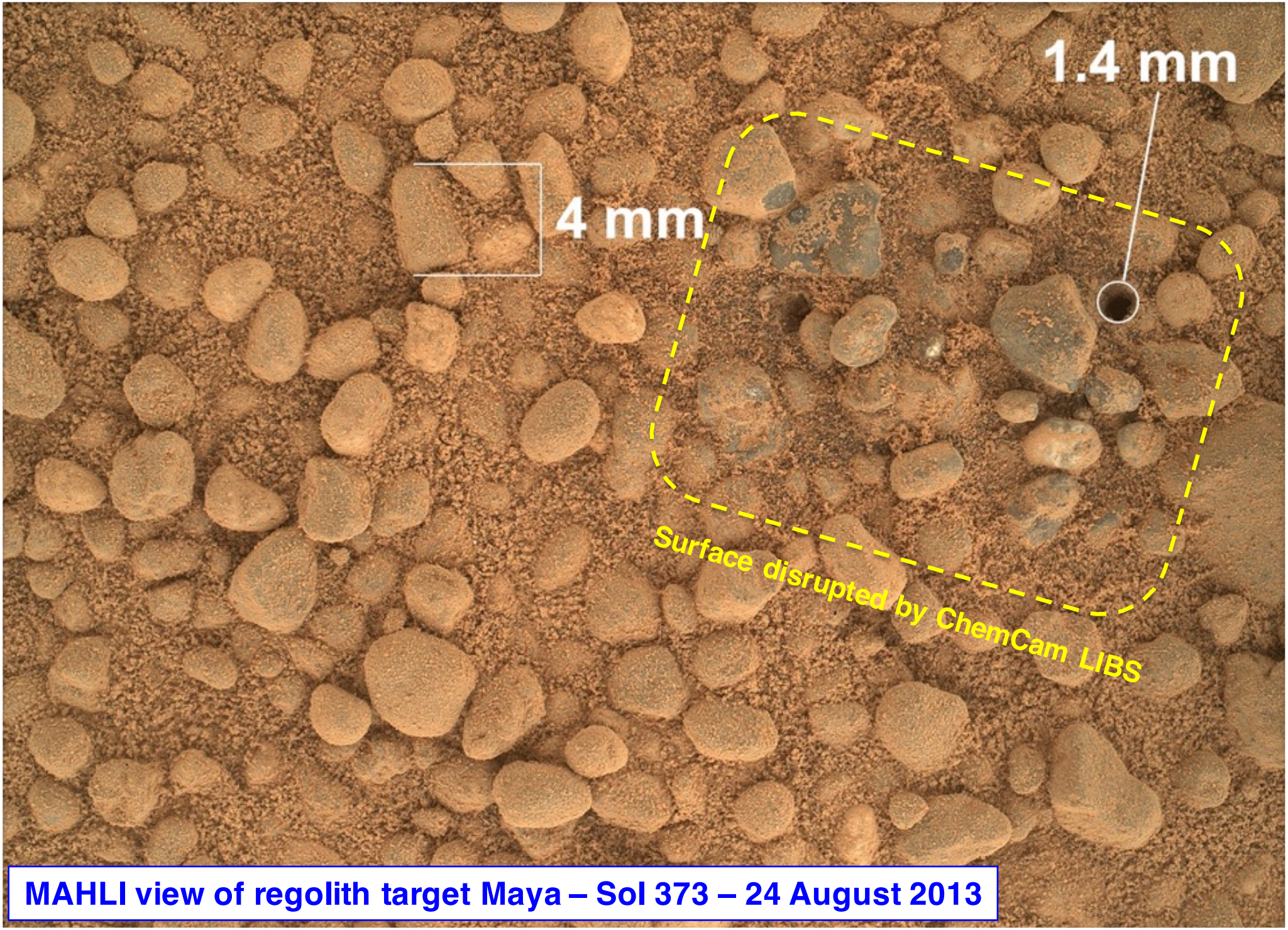
Mojave – Night Imaging – 5 cm standoff

rock target “Nova” – ChemCam laser plasma



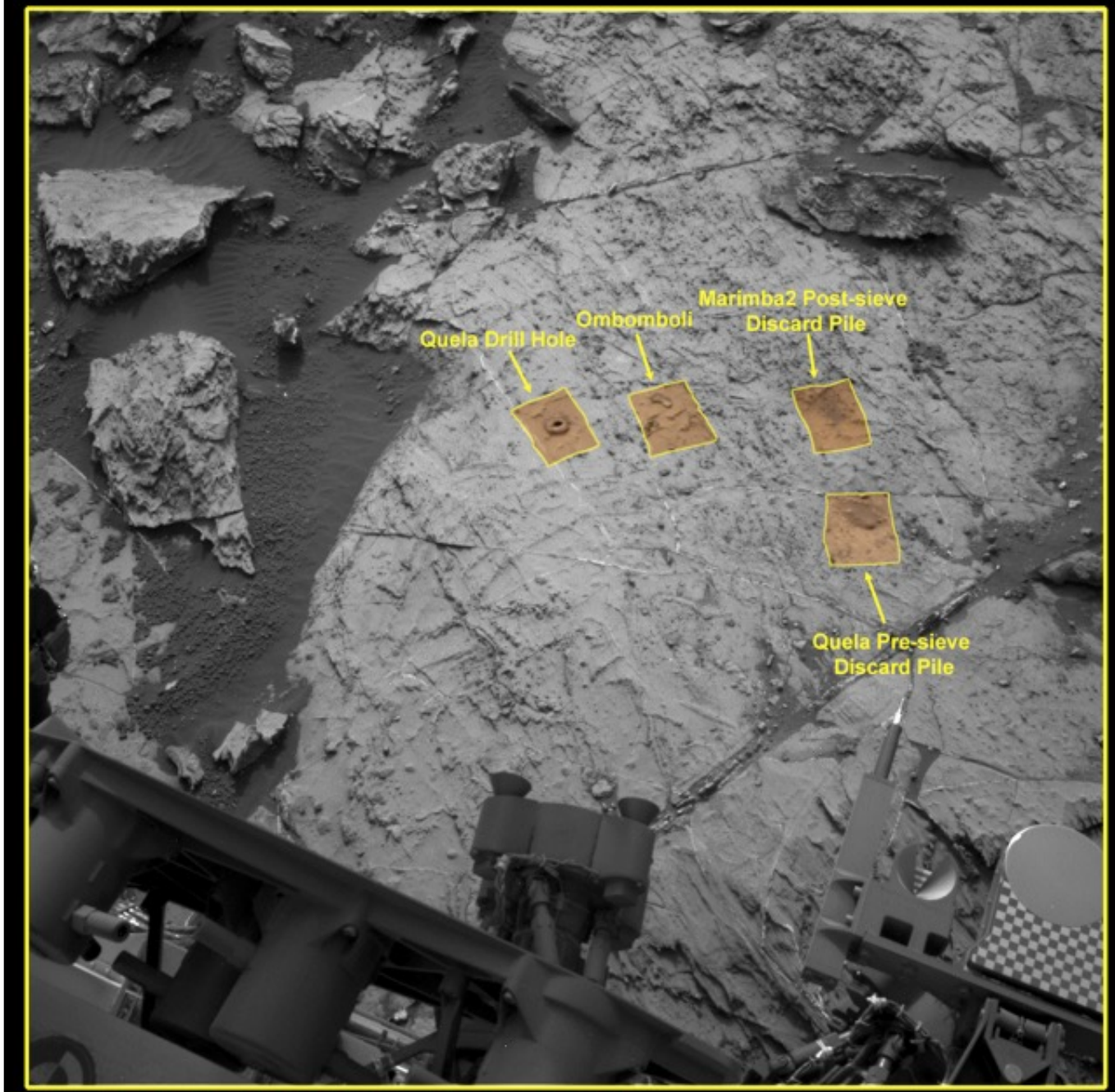
rock target “Nova” – ChemCam laser damage





MAHLI view of regolith target Maya – Sol 373 – 24 August 2013

Sols 1457-1466: Contact Science Observations
MAHLI Observations overlaid in Sol 1466 Left B Navcam



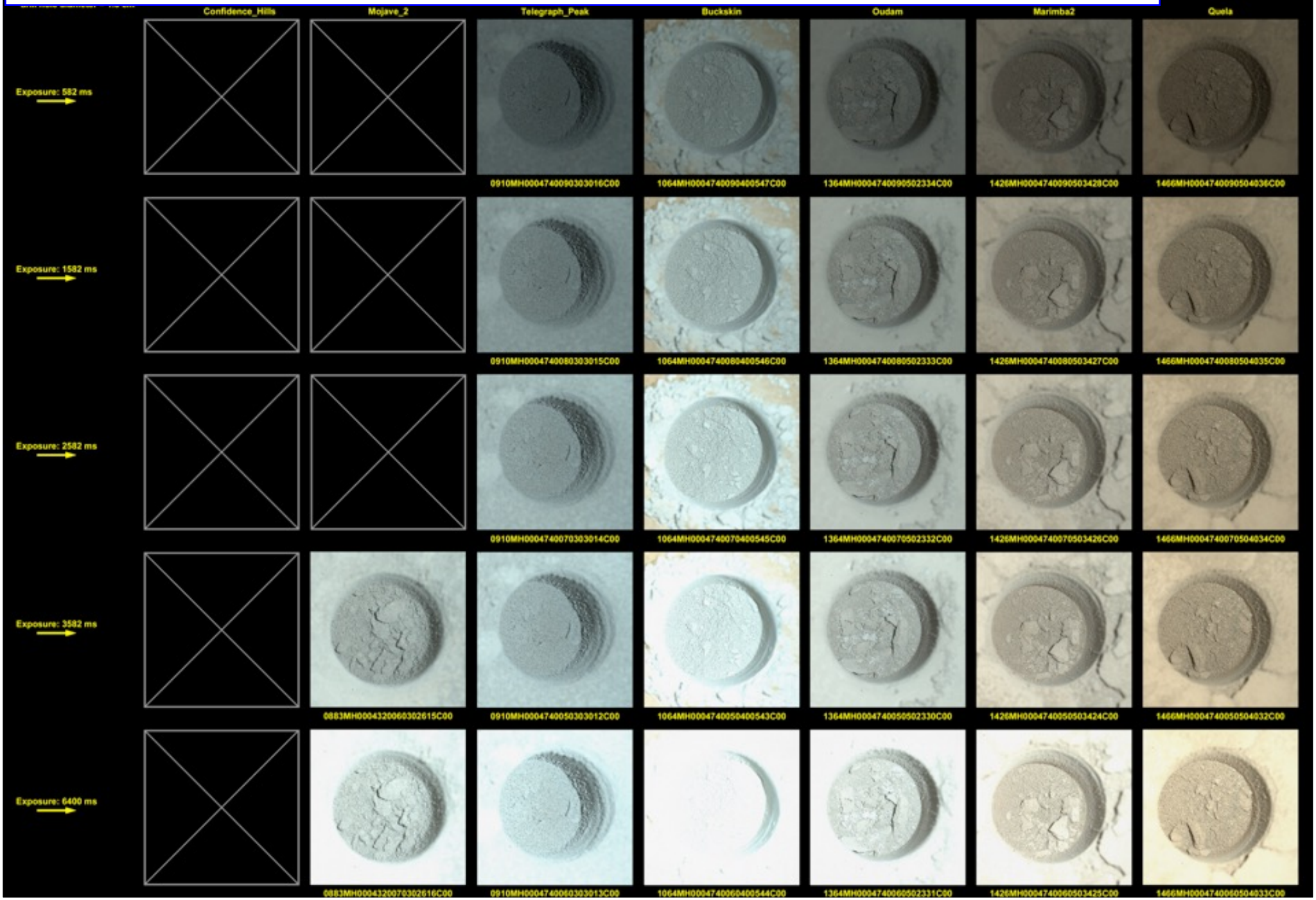
NLB_527647167EDR_F0572798NCAM00368M

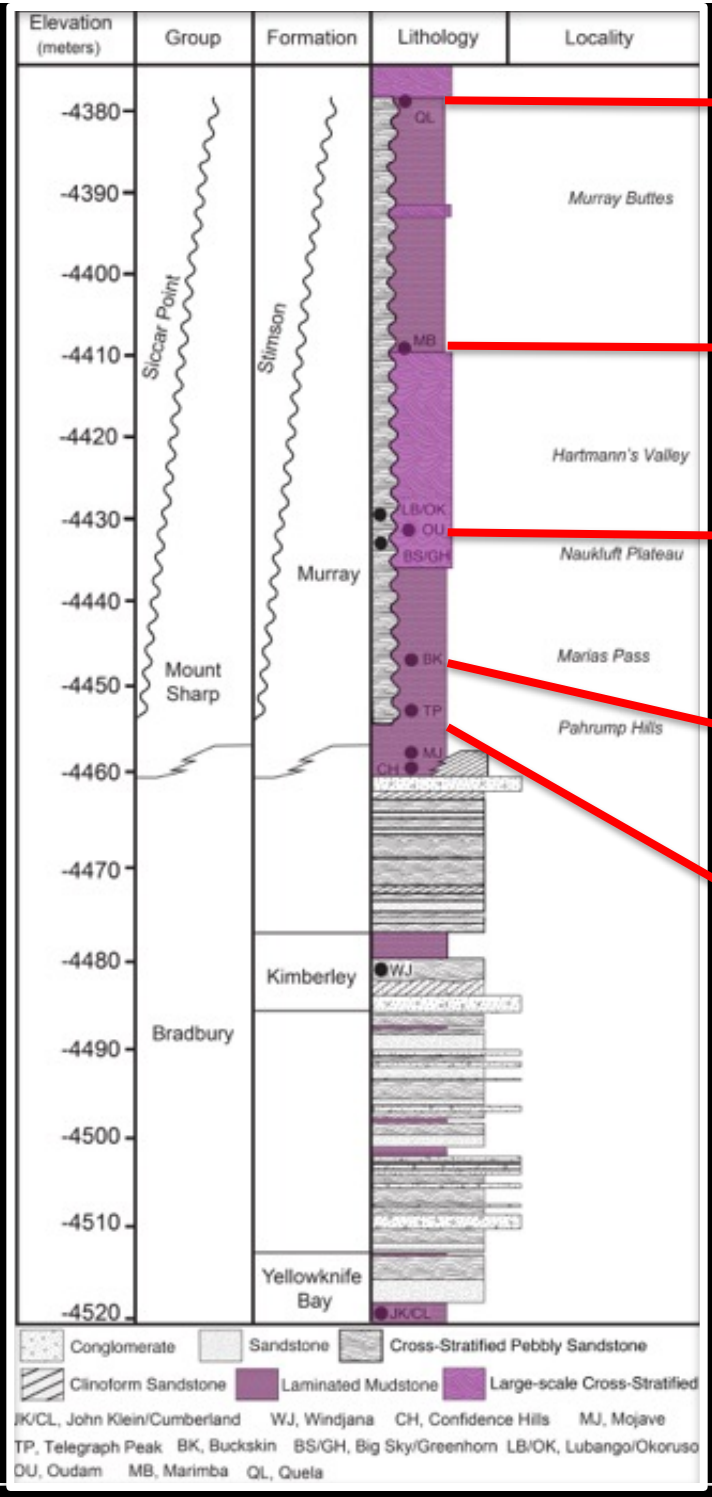
Quela drill hole – September 2016

16 mm diameter

MAHLI image 1464MH0003970010503887C00

Down Murray Mudstone Drill holes at Night – same exposure durations

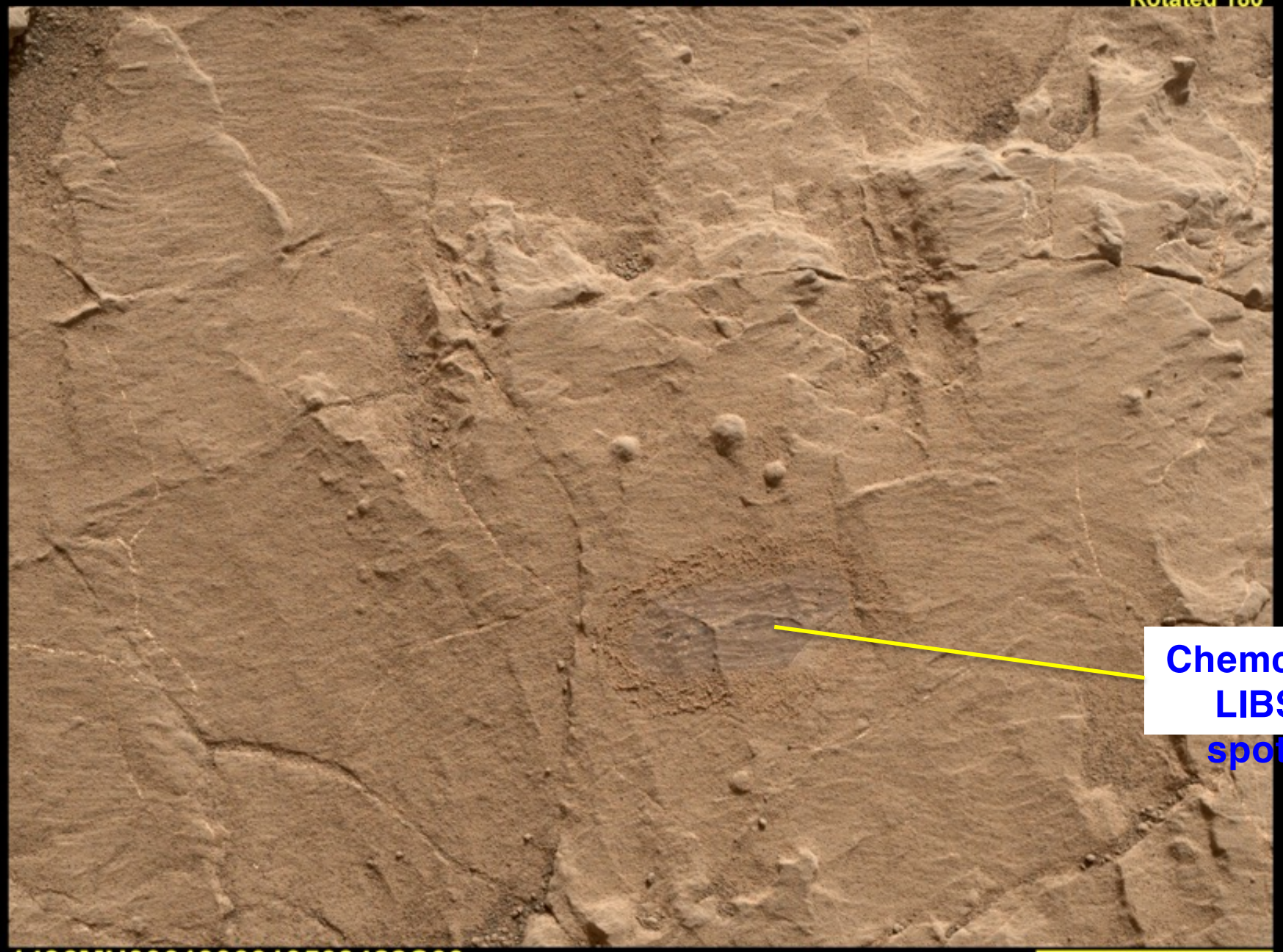




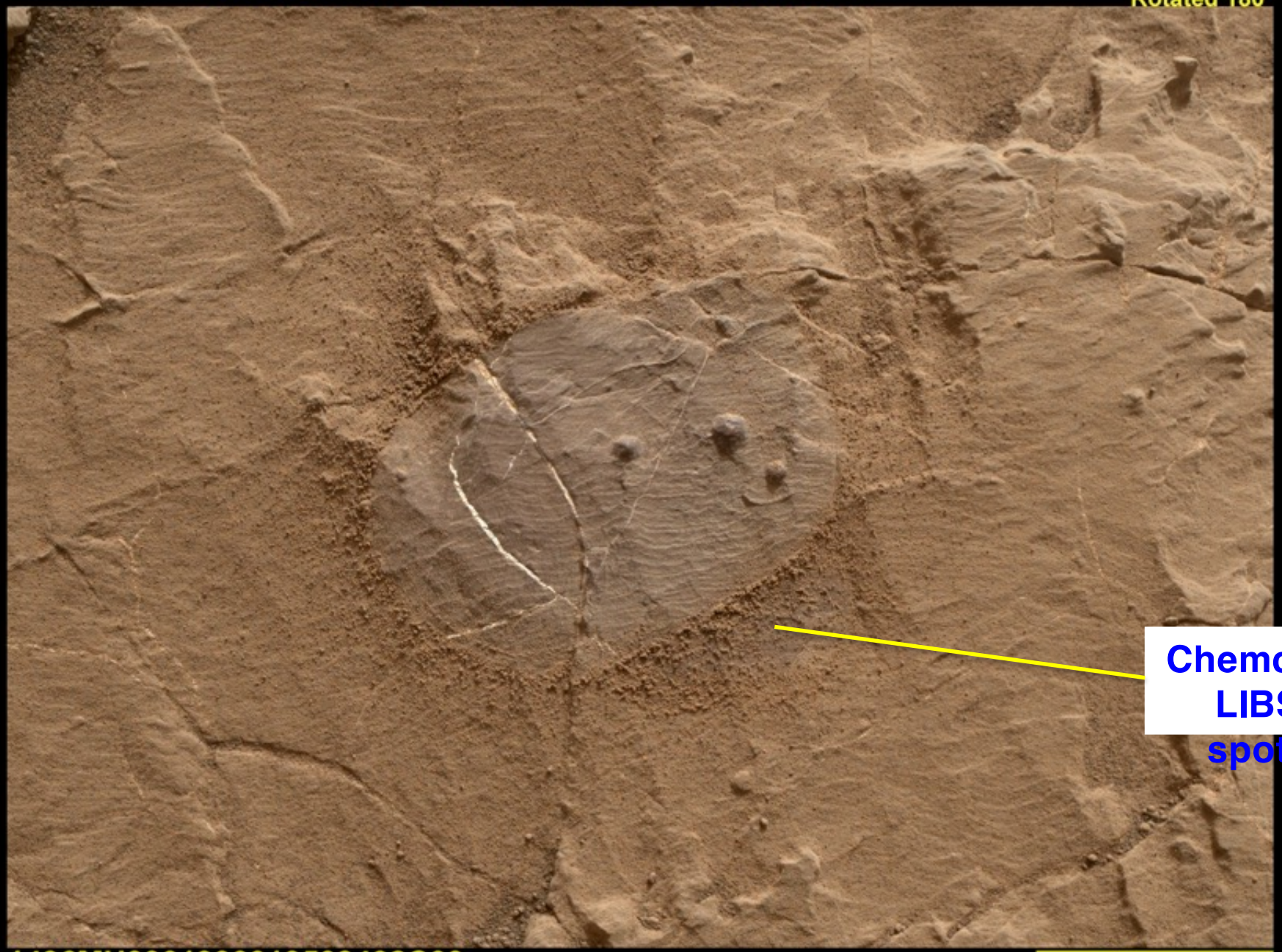
16 mm diameter drill holes

Sol 1436 – Target Conda – Before DRT – APXS and ChemCam Support

Context view from ~ 25 cm standoff

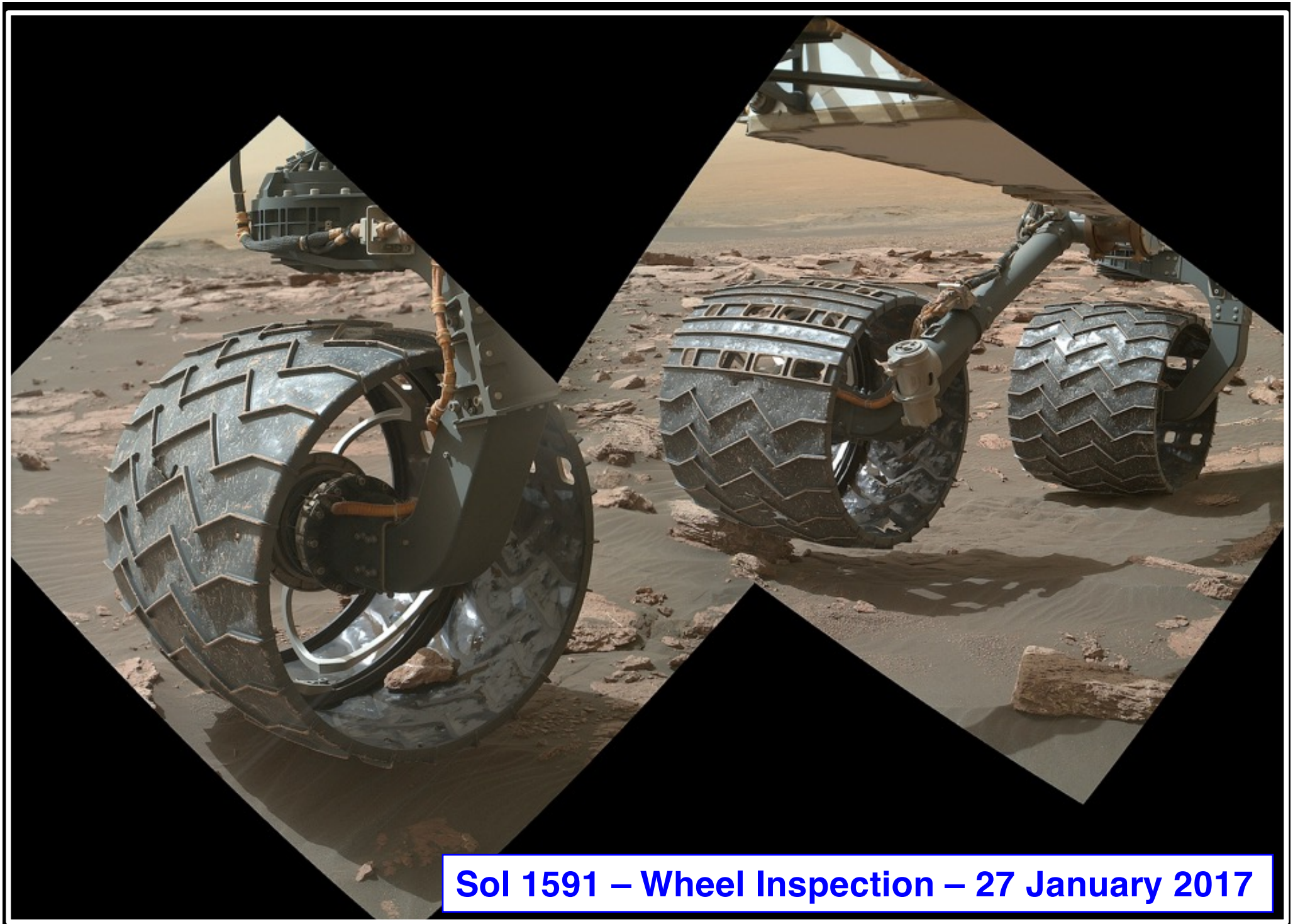


Sol 1436 – Target Conda – After DRT – APXS and ChemCam Support
Context view from ~ 25 cm standoff



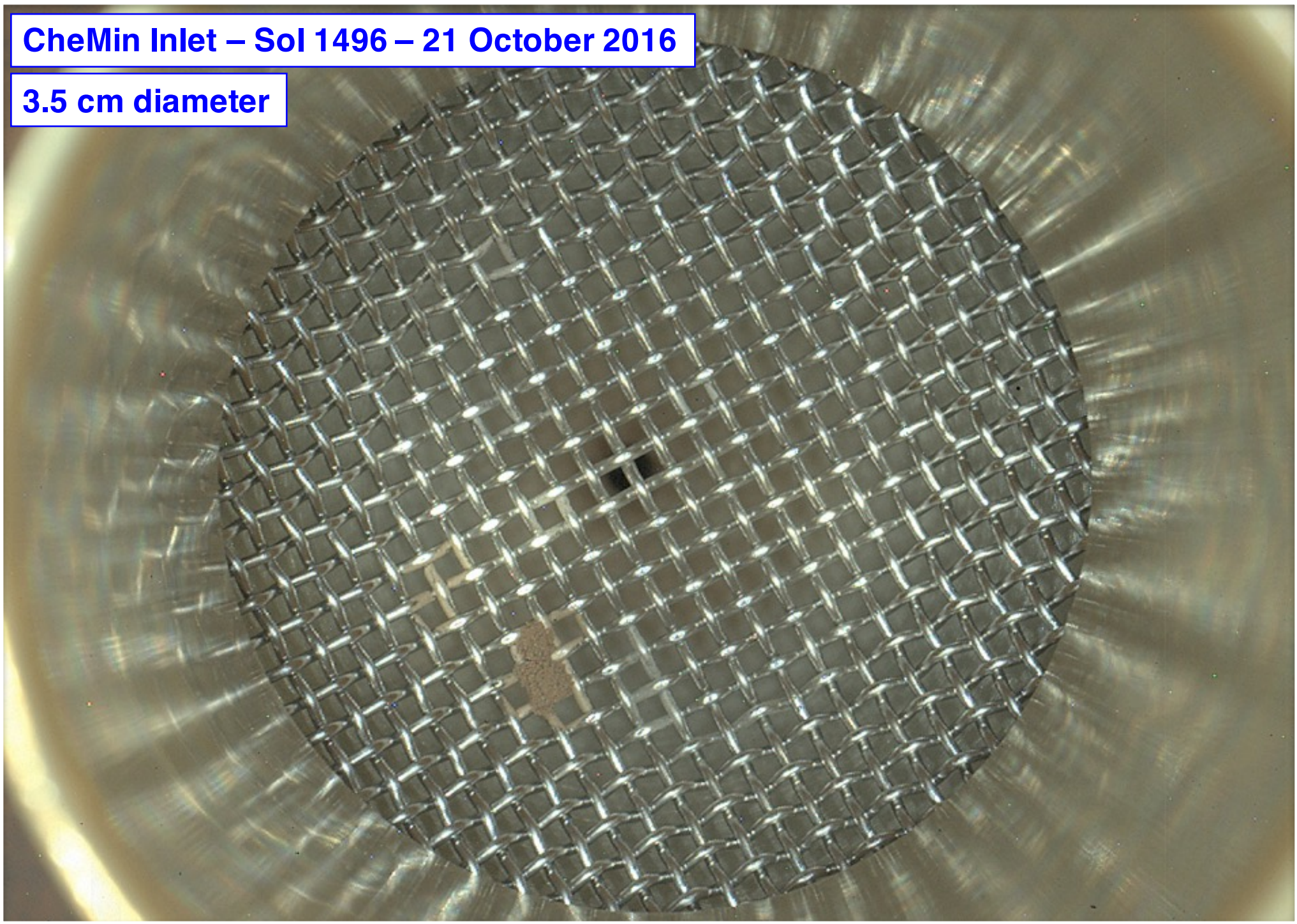
Sol 1436 – Target Conda – After DRT – APXS Support
Focus merge product from ~ 5 cm standoff

Sol 1436 – Target Conda – After DRT – APXS Support
Focus merge product from ~ 1 cm standoff



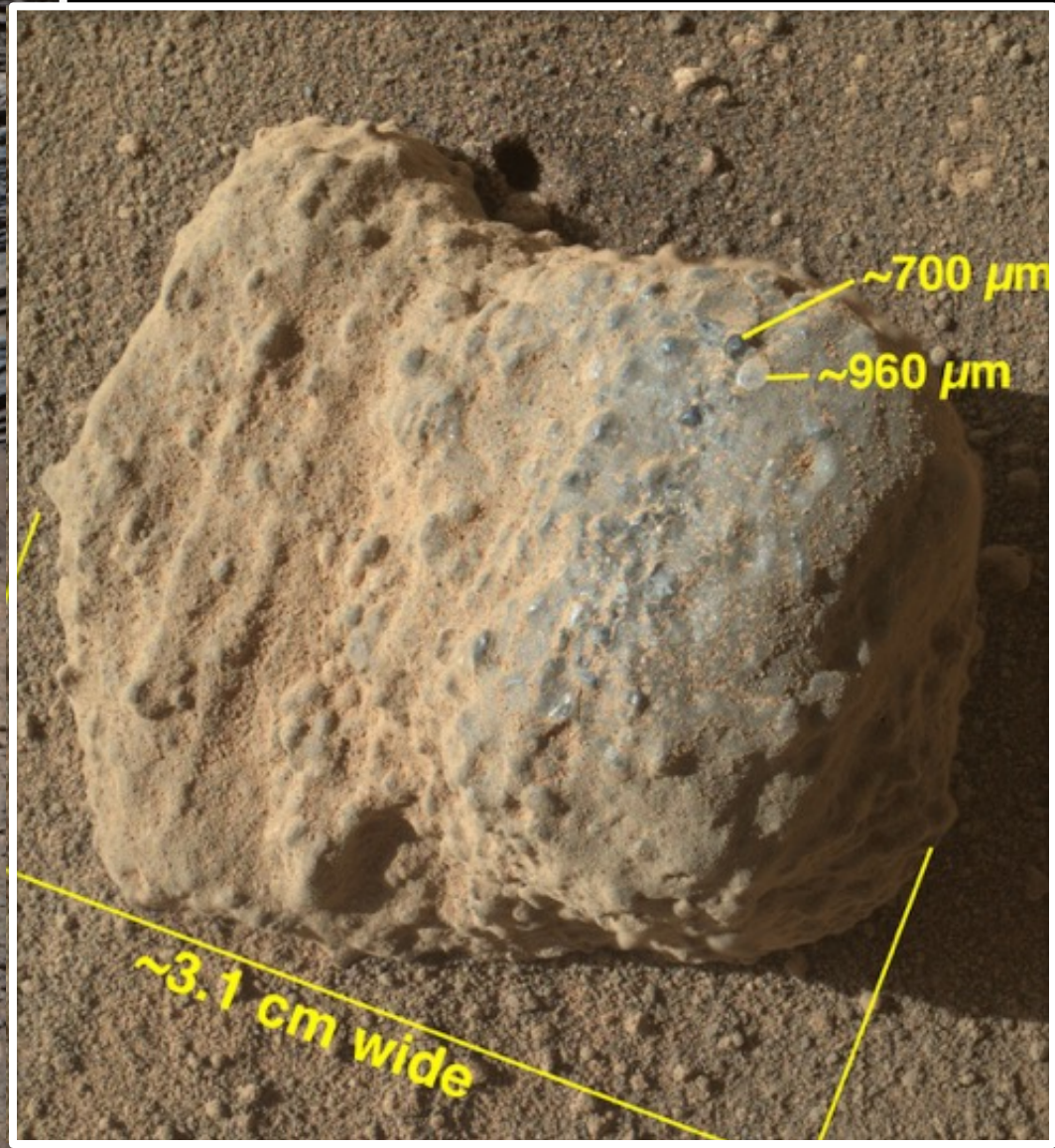
Sol 1591 – Wheel Inspection – 27 January 2017


CheMin Inlet – Sol 1496 – 21 October 2016
3.5 cm diameter


CheMin Inlet – Sol 1496 – 21 October 2016
3.5 cm diameter

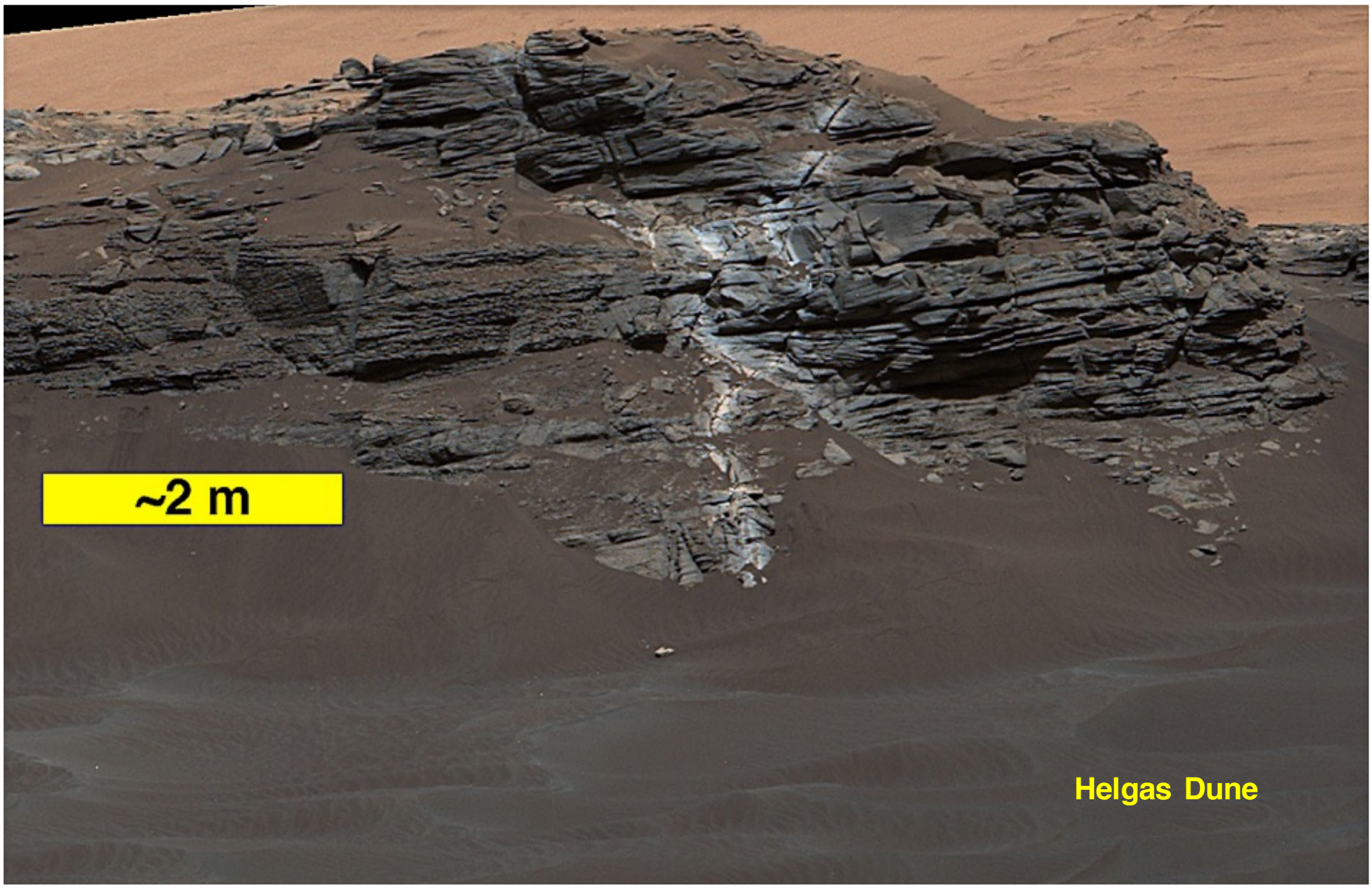
CONCRETIONS

Nosib – Sol 1277 – M-100 mcam05998

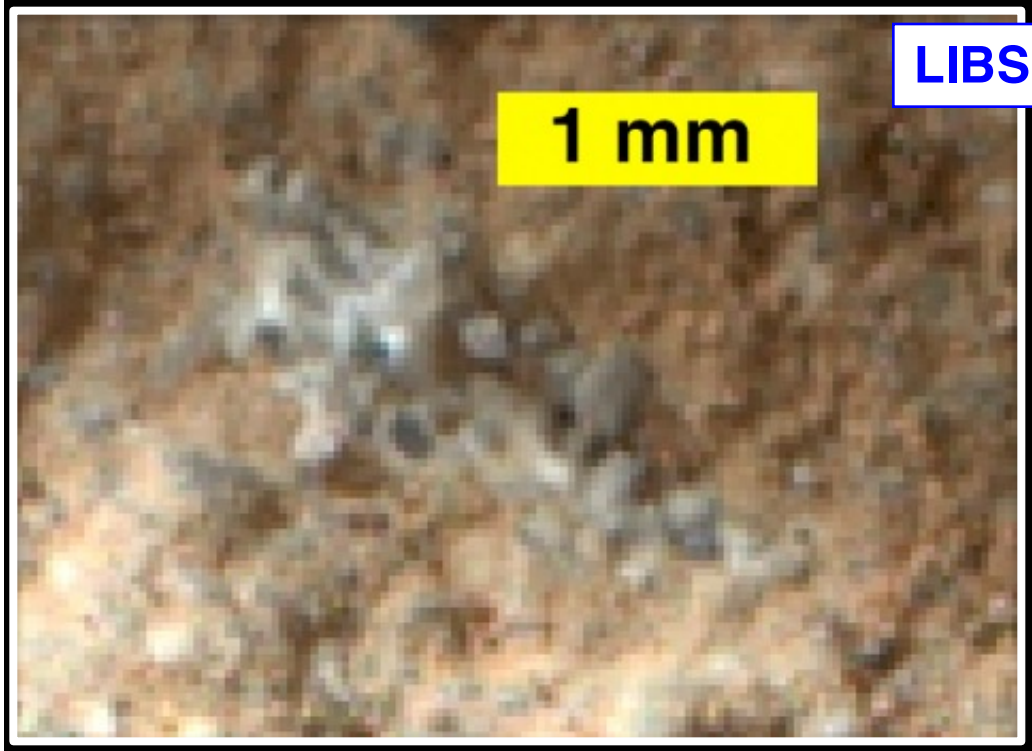


MAHLI focus merge product
1278MH0001700000500009R00

Fracture-associated halo in Stimson eolian sandstone



view toward ~east-southeast, Sol 1381 M-100 mosaic mcam06770

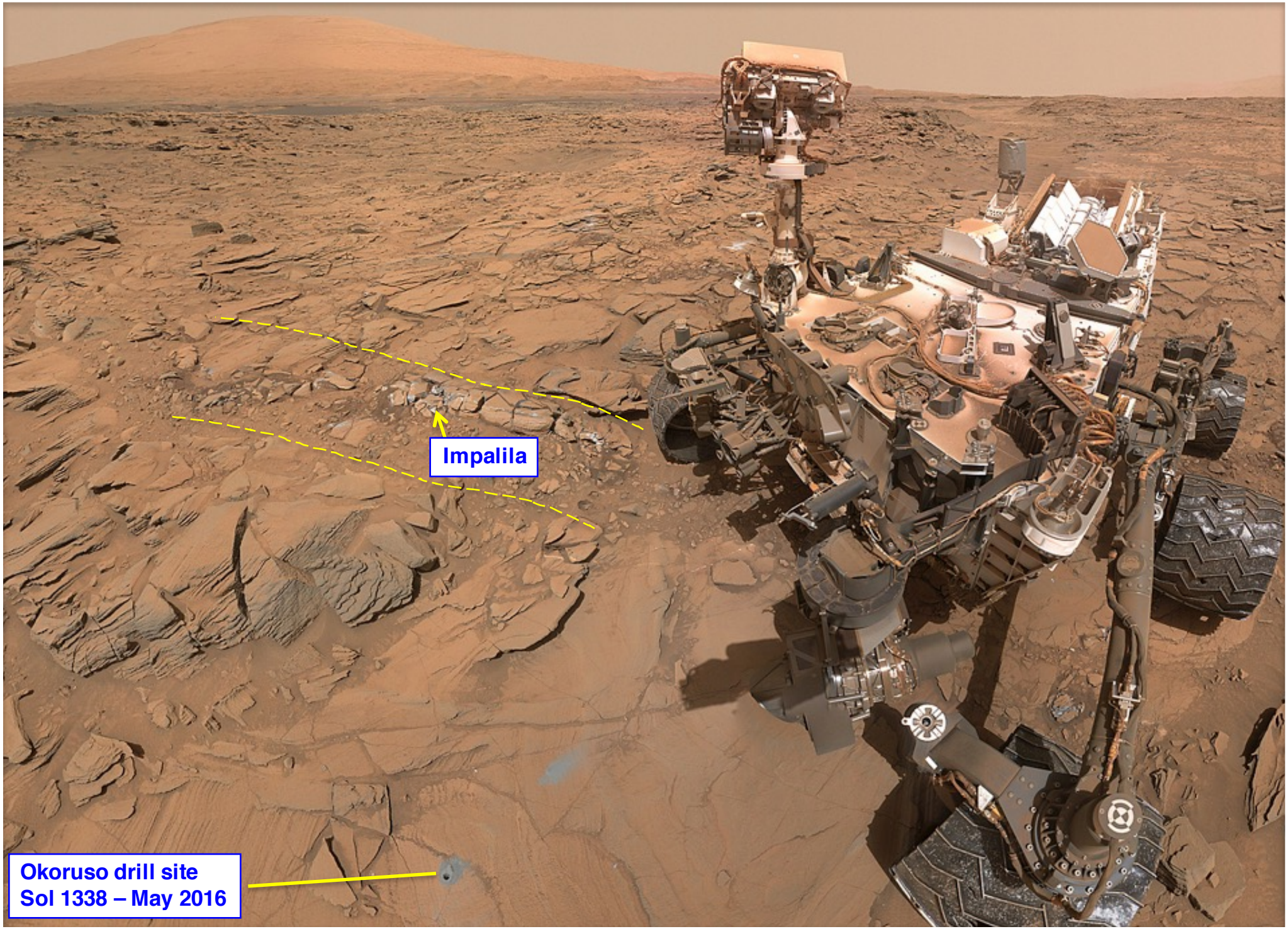


LIBS spot #5

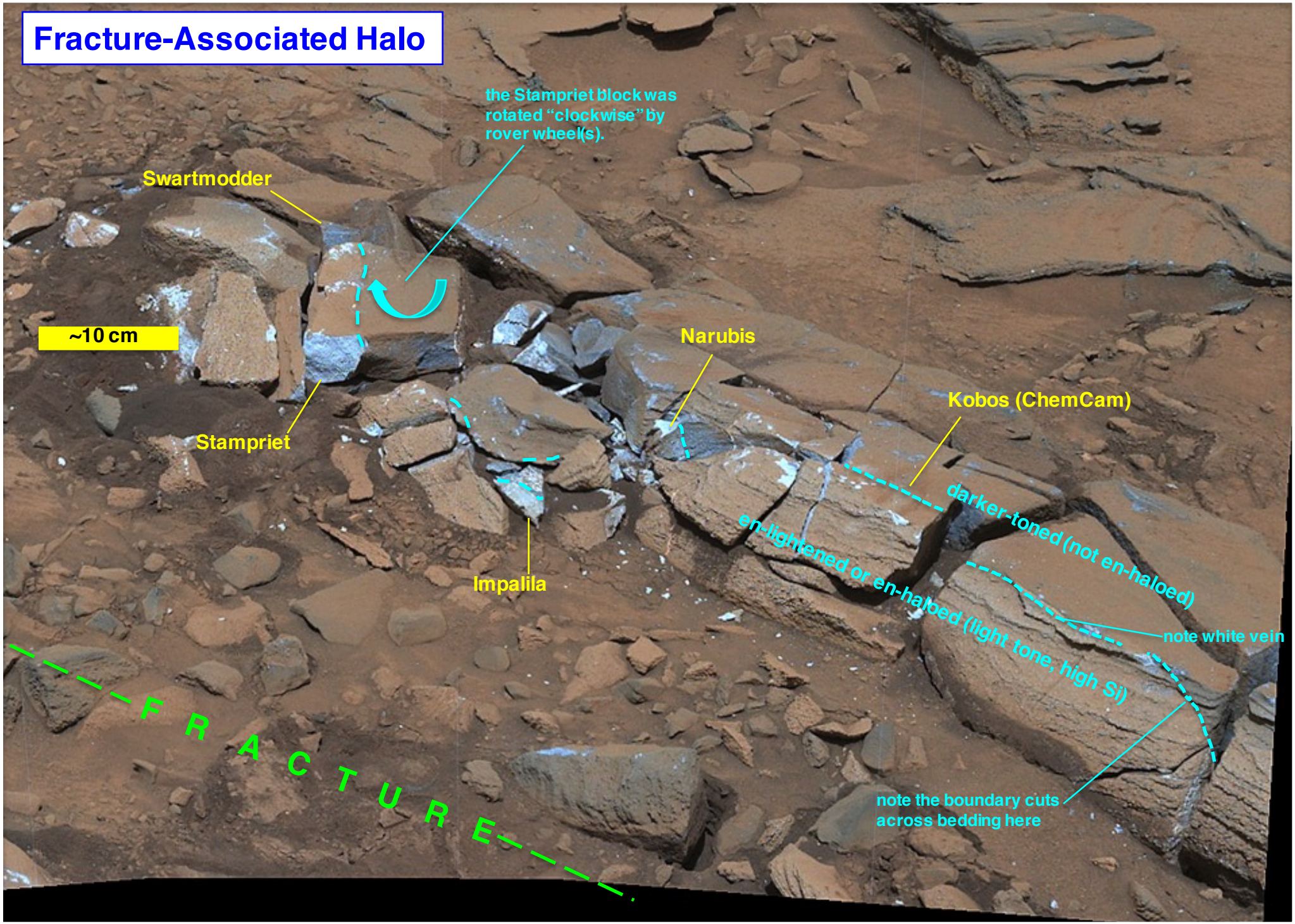
LIBS spot #7

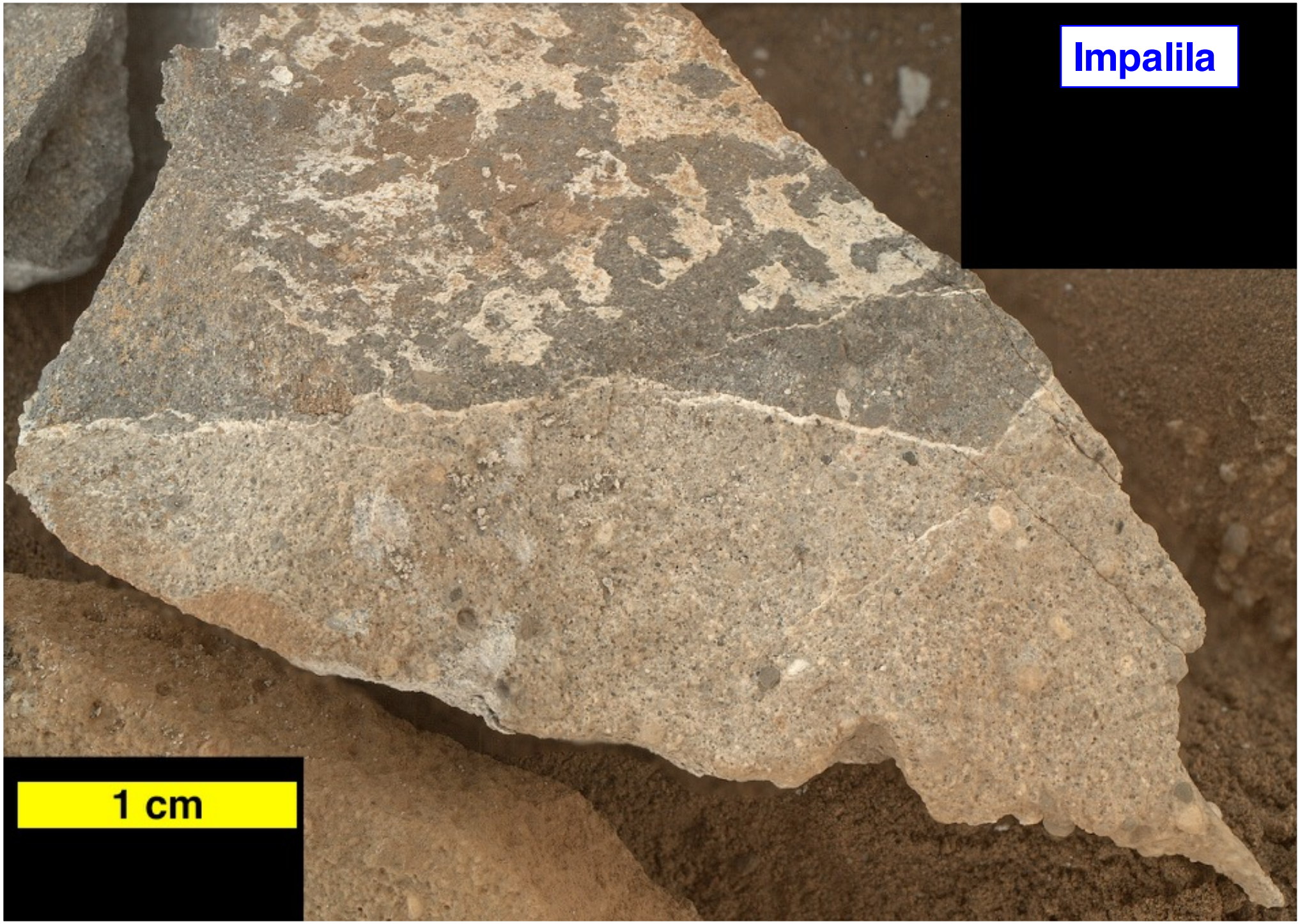
Vandalia (Sol 1143)
APXS & MAHLI

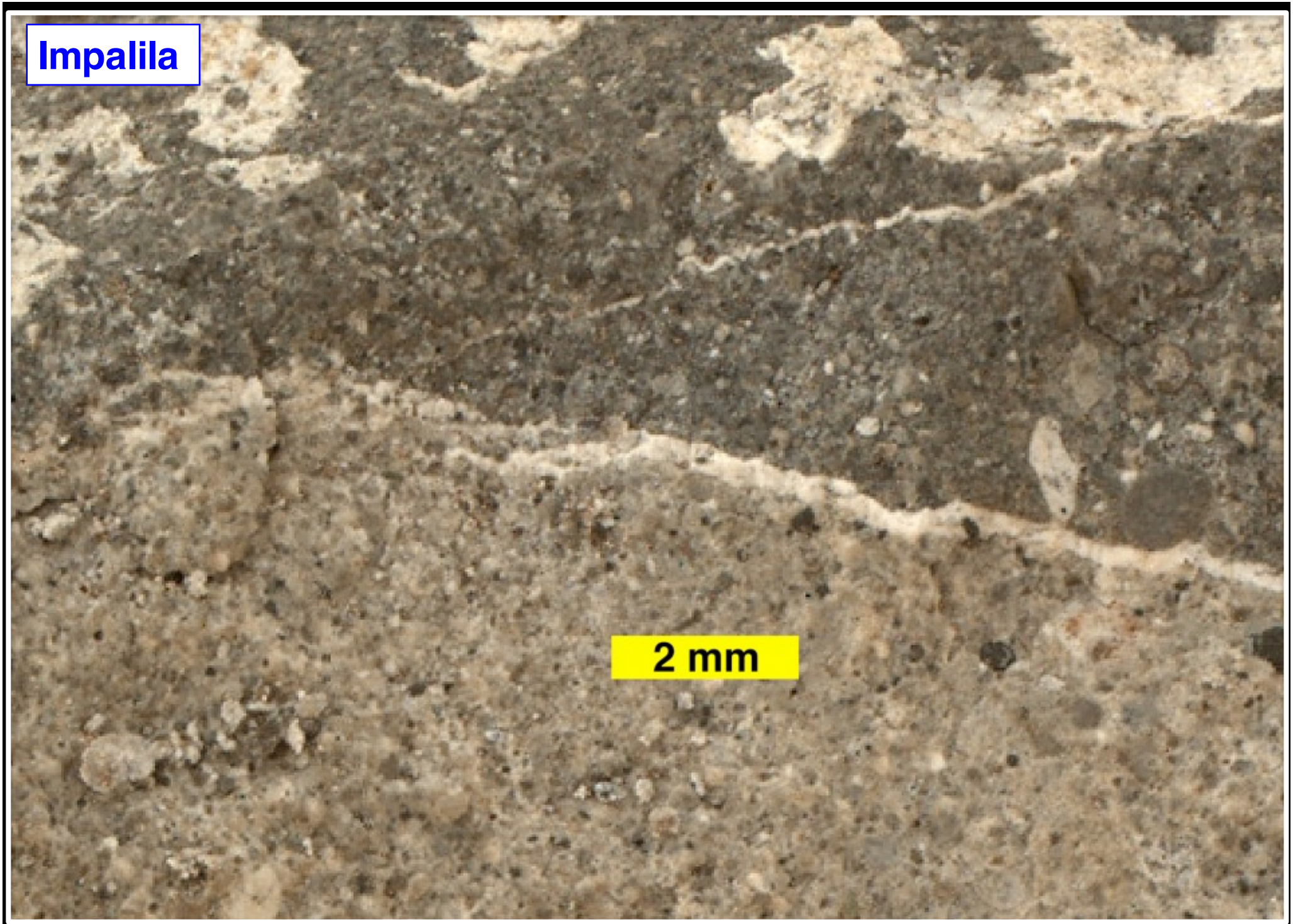
Devils Basin (Sol 1120)
ChemCam

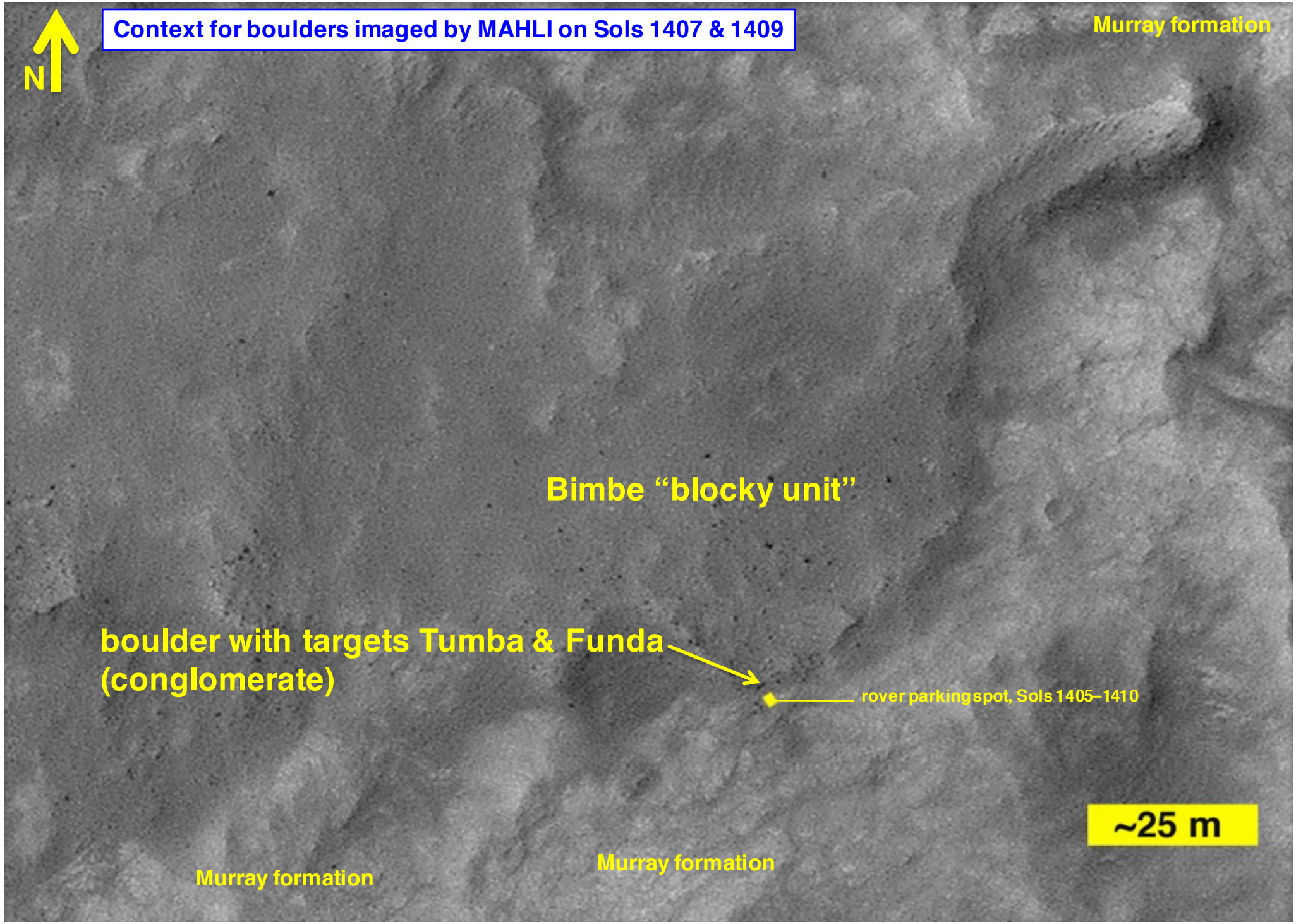

Impalila
Okoruso drill site
Sol 1338 – May 2016

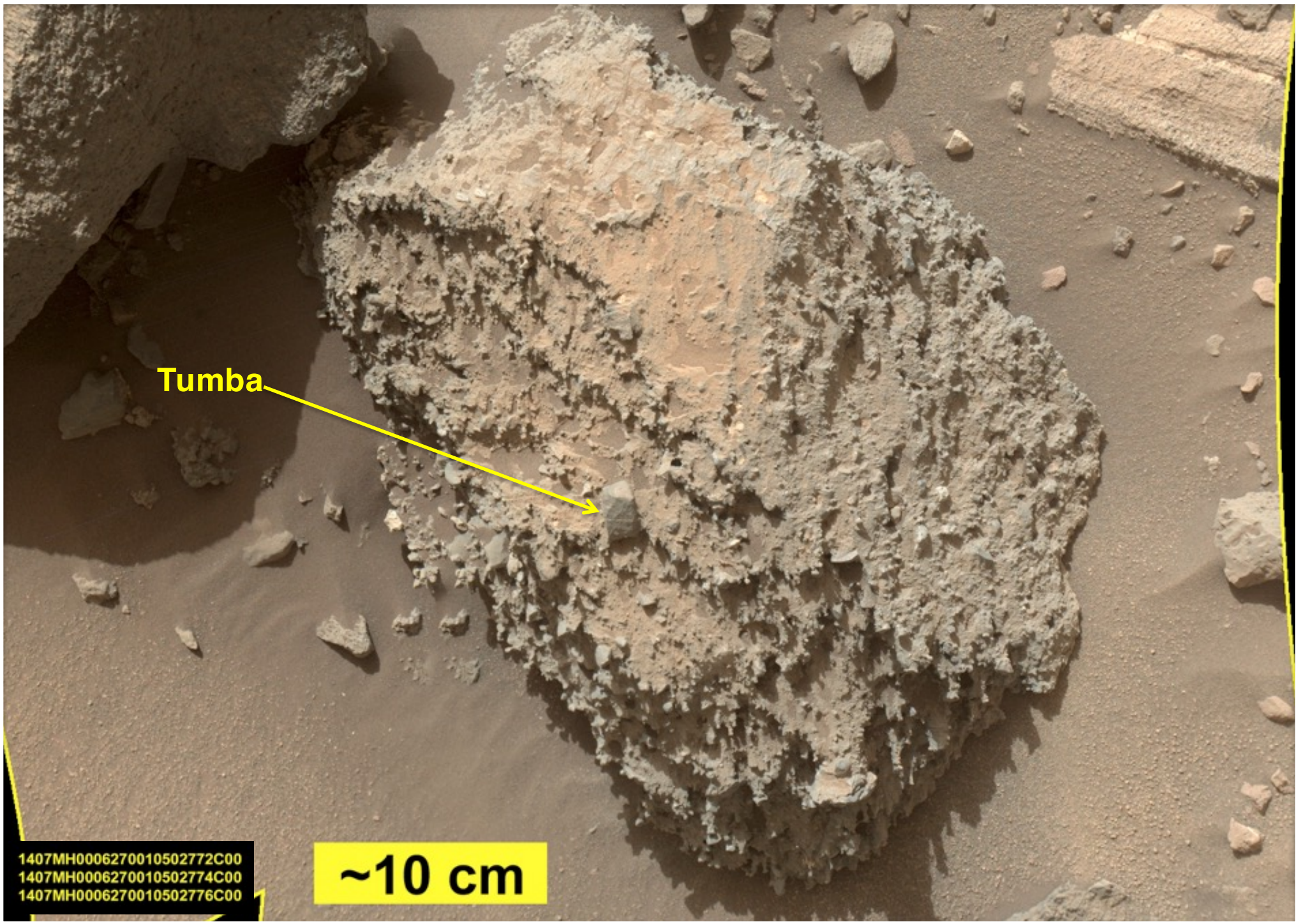
Fracture-Associated Halo



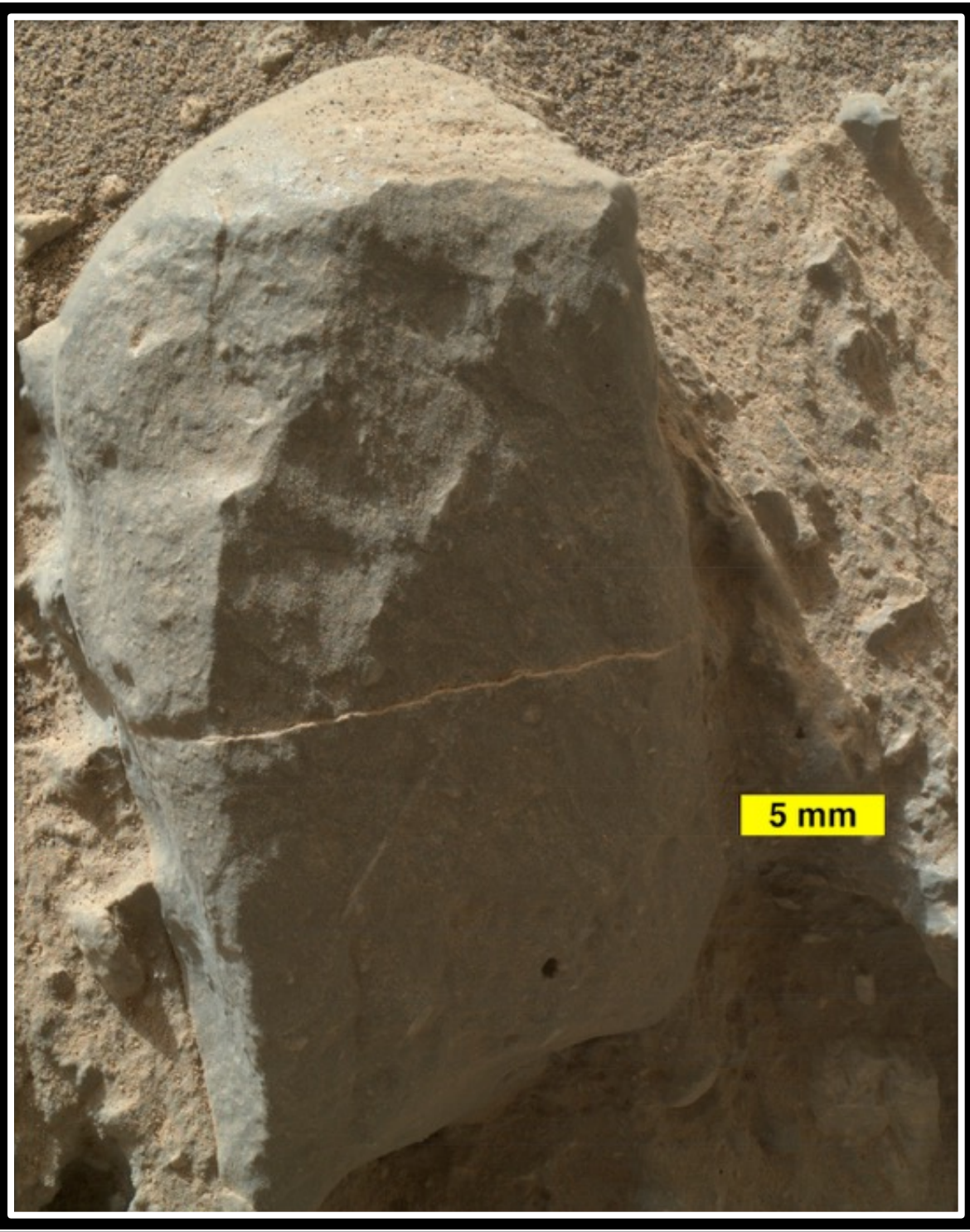

Impalila
1 cm

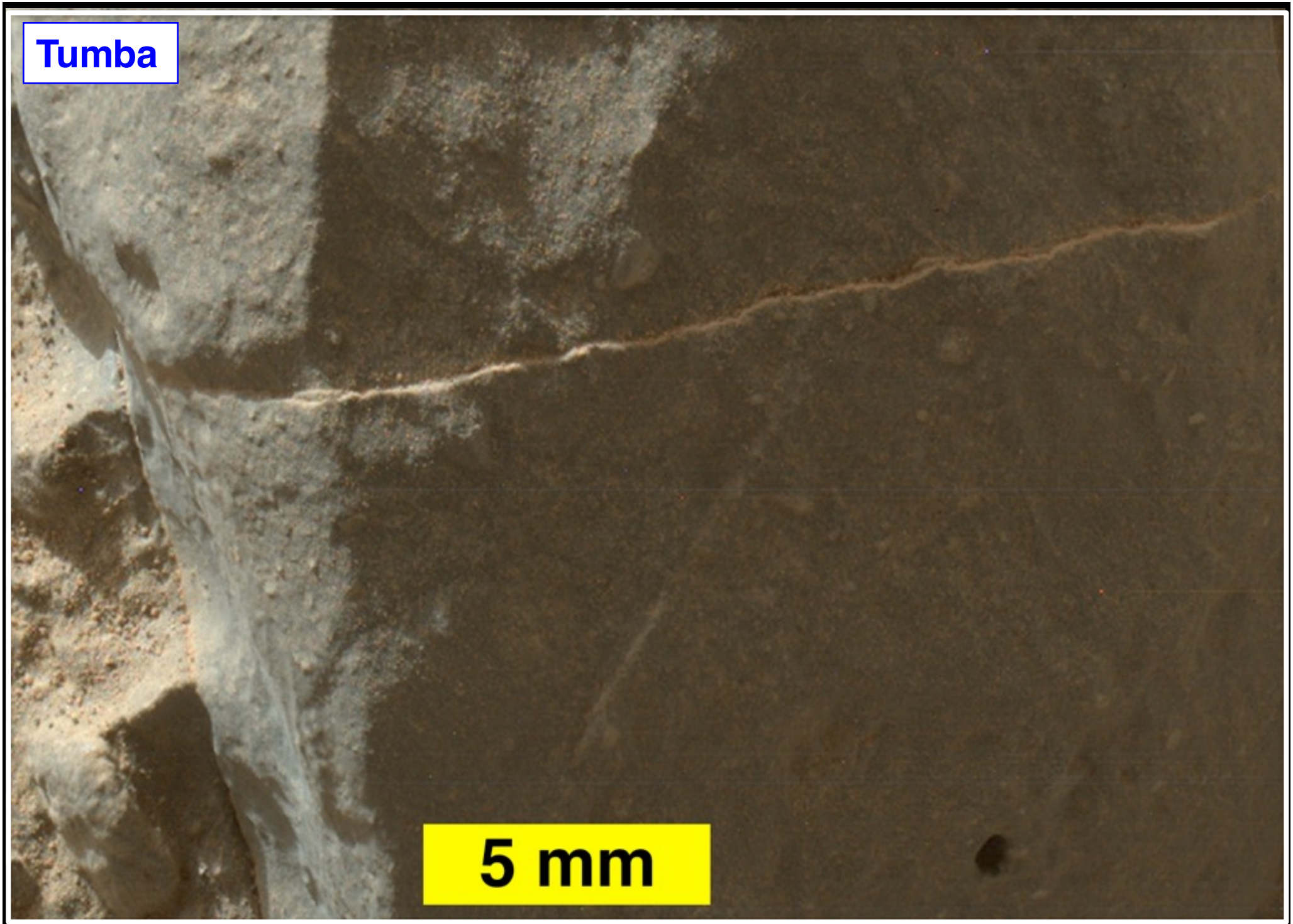

Impalila
2 mm

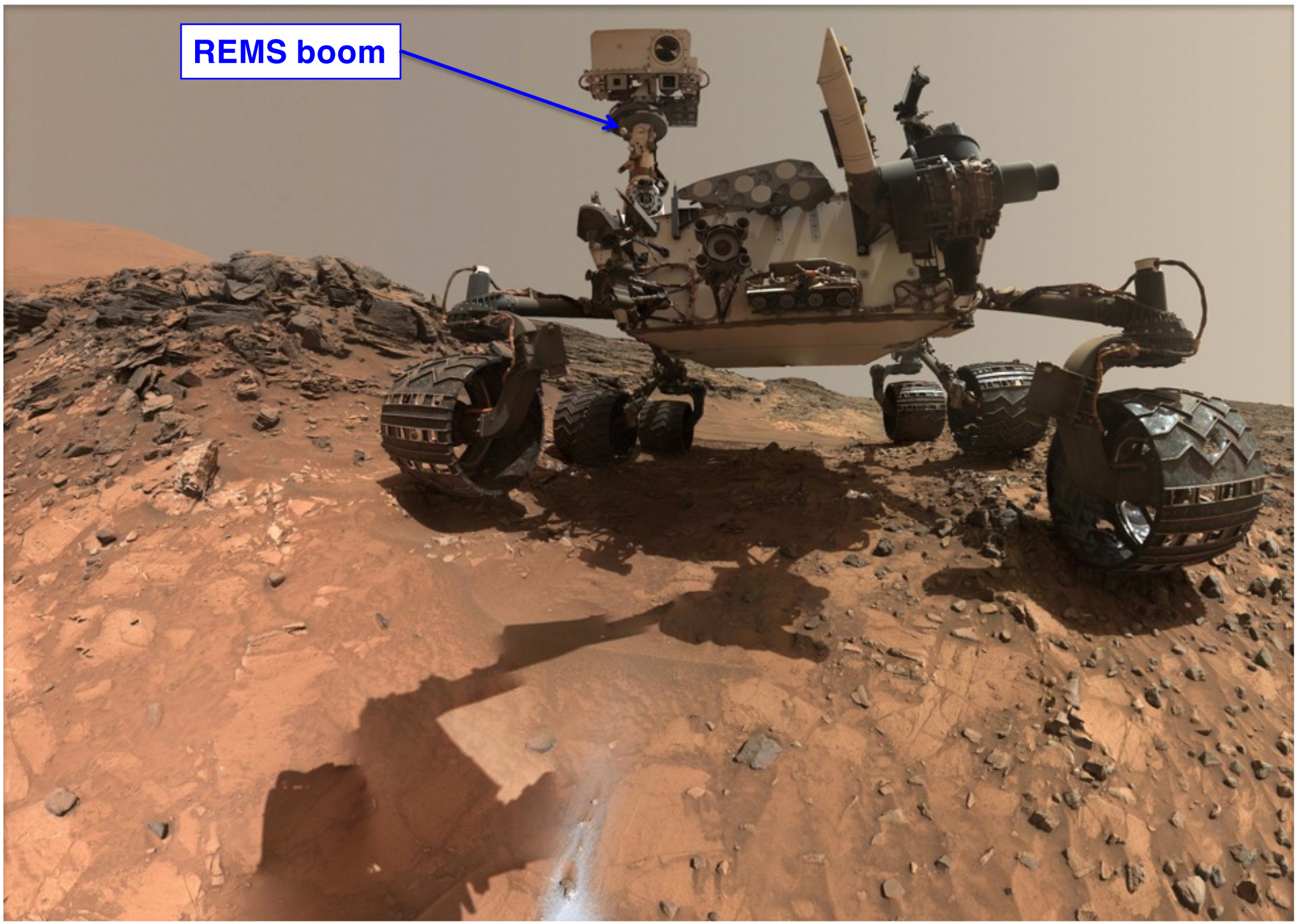

N
Context for boulders imaged by MAHLI on Sols 1407 & 1409
Murray formation
Bimbe "blocky unit"
boulder with targets Tumba & Funda (conglomerate)
rover parking spot, Sols 1405–1410
~25 m
Murray formation
Murray formation


Tumba
1407MH0006270010502772C00
1407MH0006270010502774C00
1407MH0006270010502776C00
~10 cm

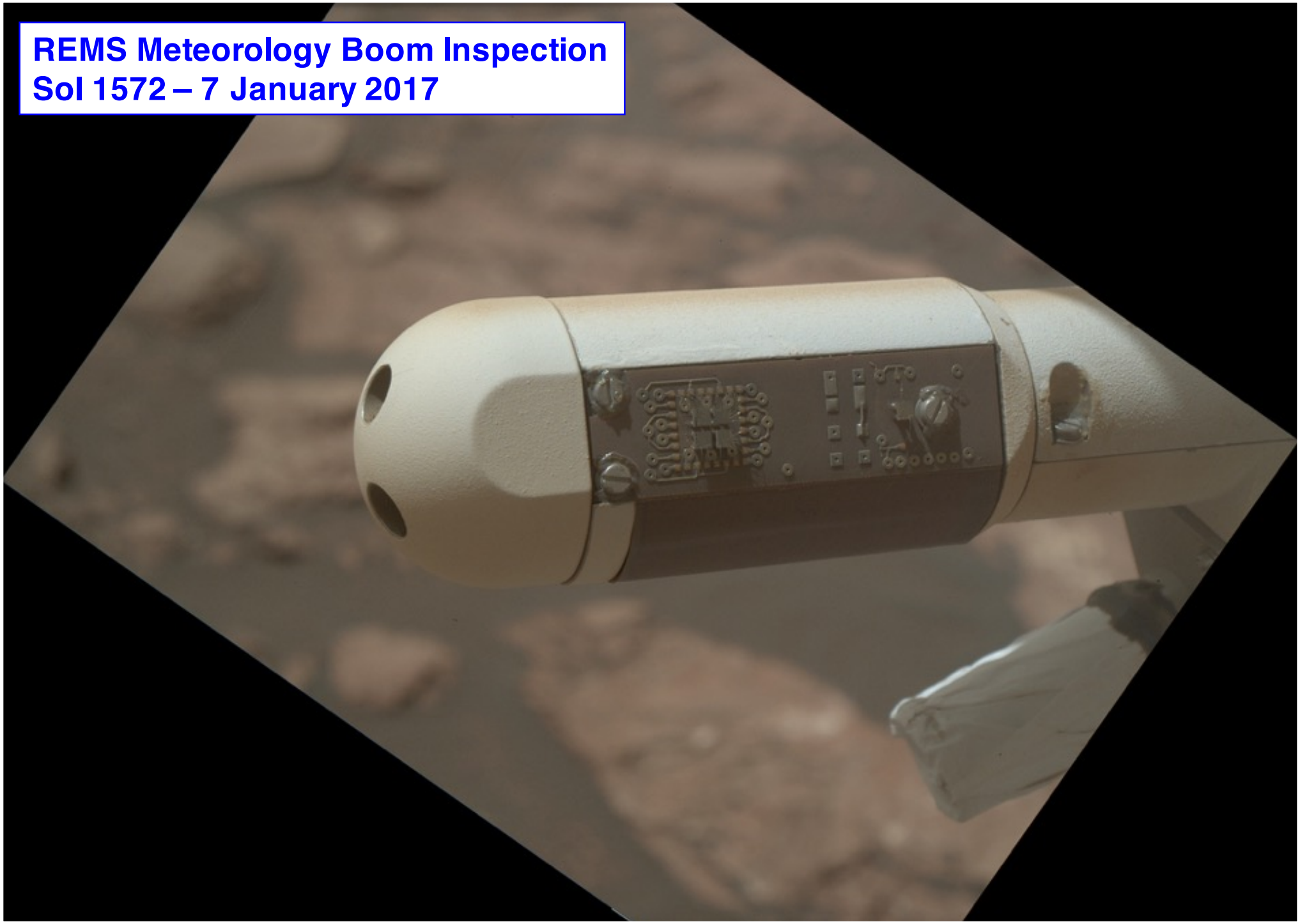
Tumba



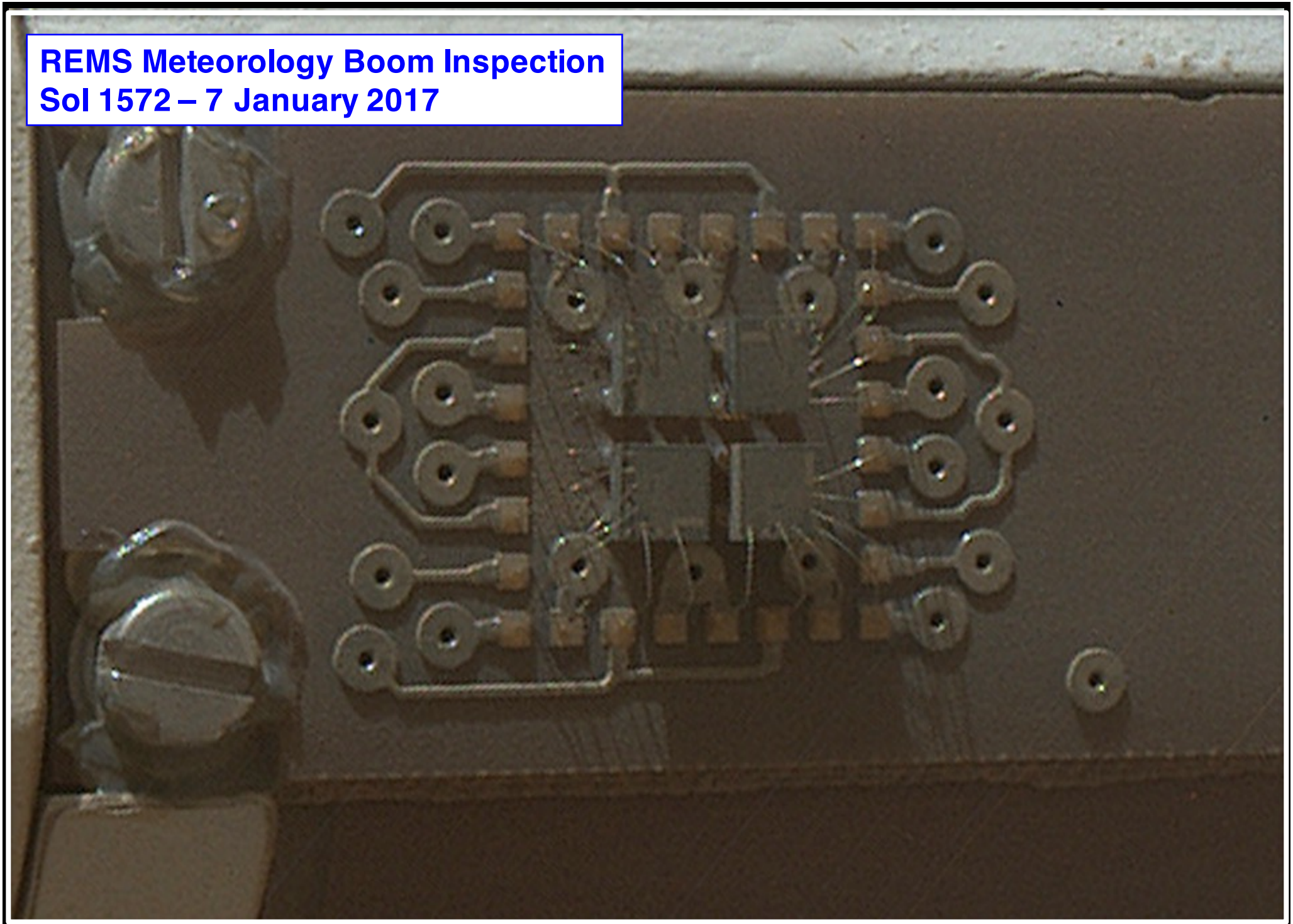

Tumba
5 mm

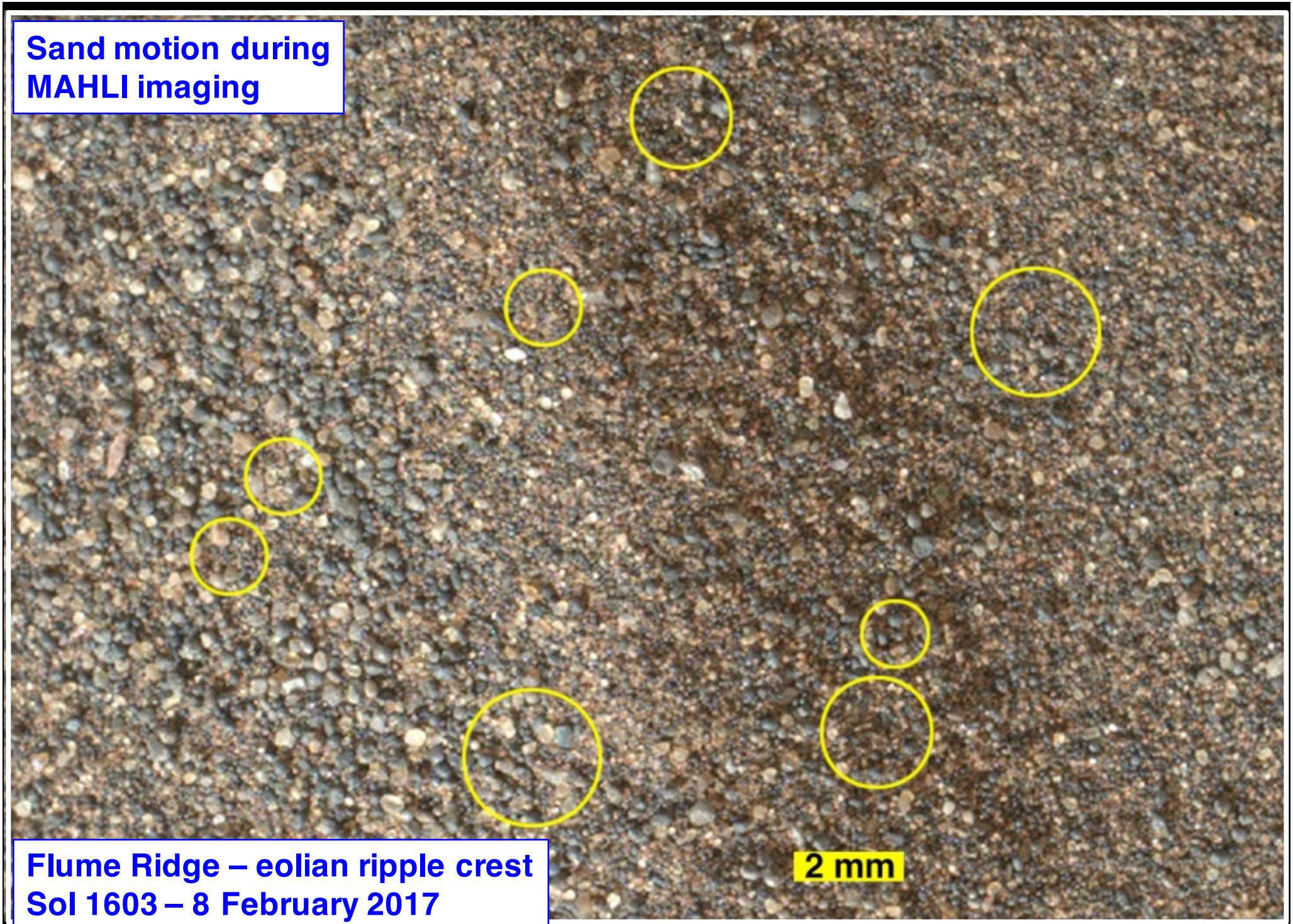

REMS boom

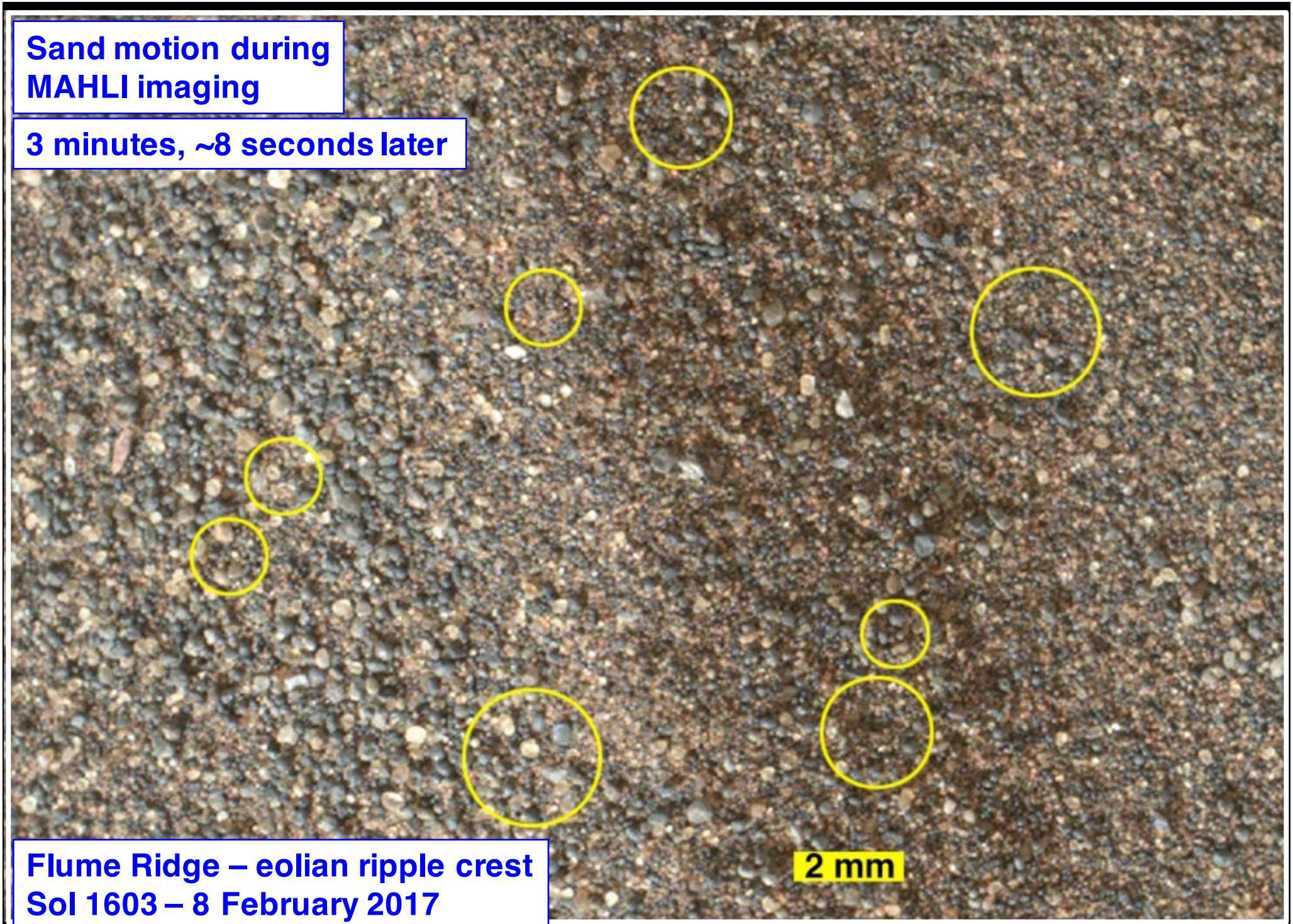
REMS Meteorology Boom Inspection
Sol 1572 – 7 January 2017



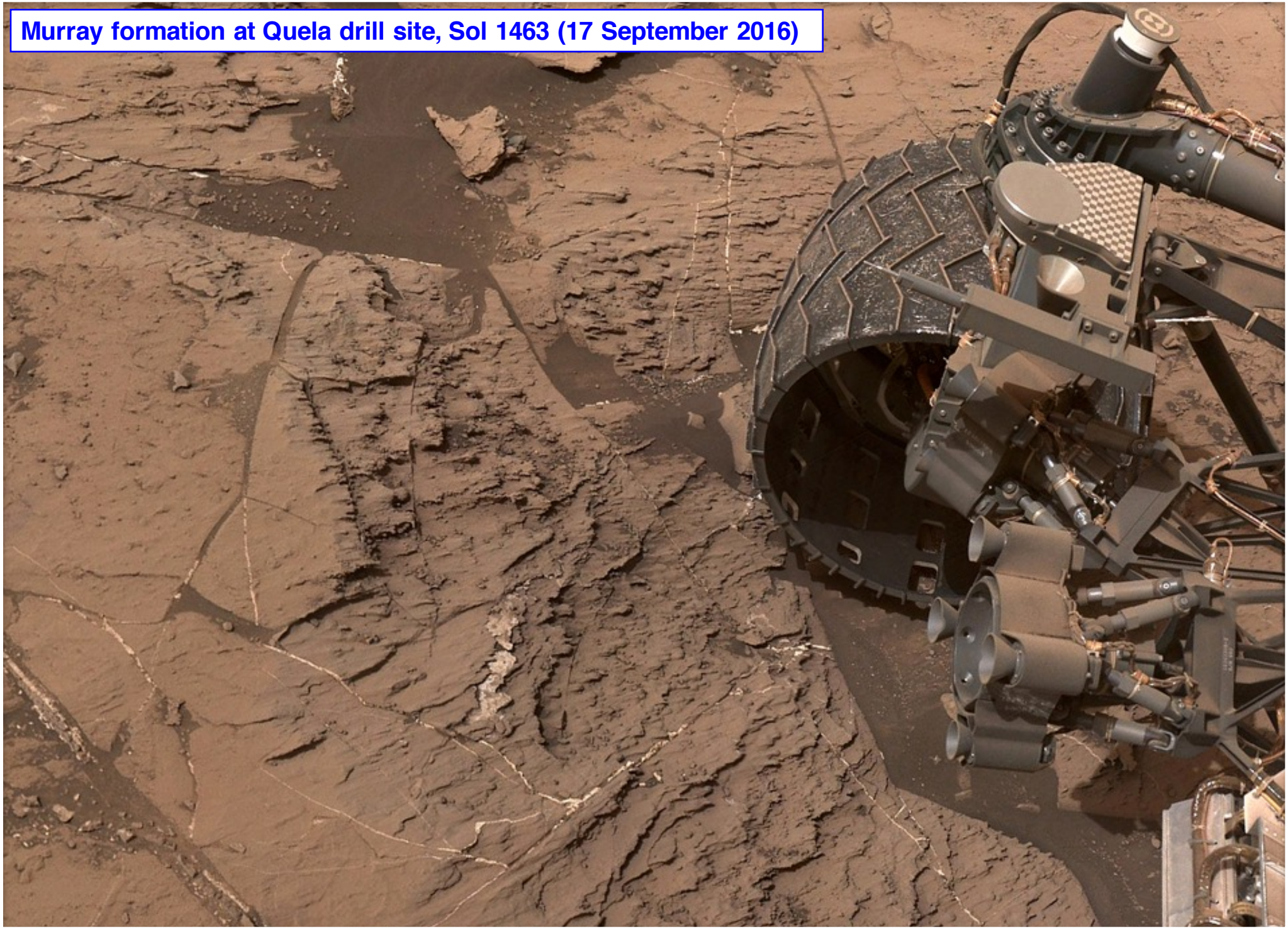
REMS Meteorology Boom Inspection
Sol 1572 – 7 January 2017




Sand motion during MAHLI imaging
2 mm
Flume Ridge – eolian ripple crest
Sol 1603 – 8 February 2017


Sand motion during MAHLI imaging
3 minutes, ~8 seconds later
Flume Ridge – eolian ripple crest
Sol 1603 – 8 February 2017
2 mm

Murray formation at Quela drill site, Sol 1463 (17 September 2016)



(additional slides...)

MAHLI Technical Reports

For more information about MAHLI calibration, characterization, image range and scale, focus merge products, etc.

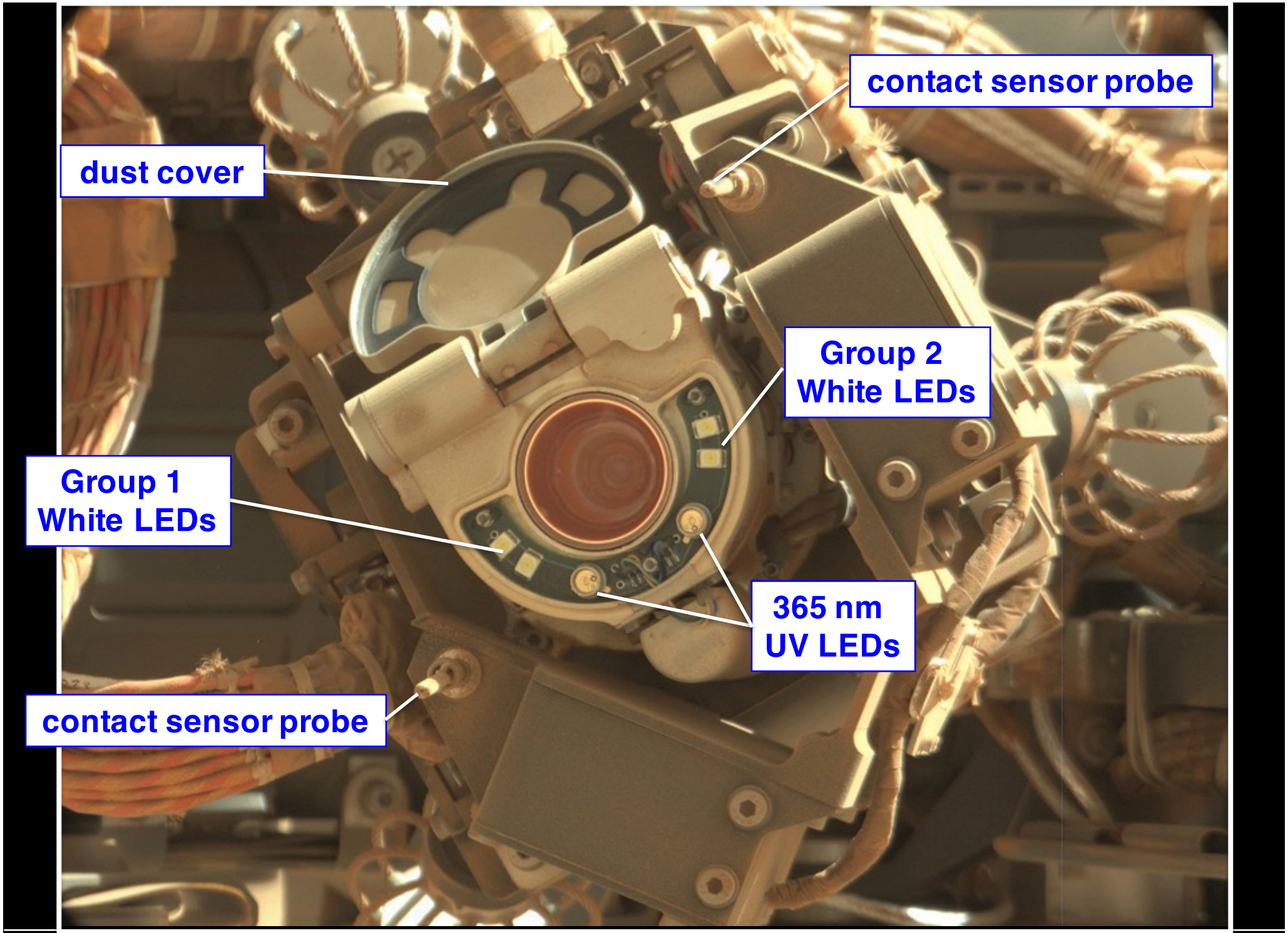
Report	Title	Date	DOI
0001	Curiosity's robotic arm-mounted Mars Hand Lens Imager (MAHLI): Characterization and calibration status **New as of 5-Oct-2015: Equation 2 of Rept 0001 has been corrected; please download the appropriate "Supplementary File" for the updated MAHLI Cal Report.** **New as of 4-Dec-2015: The corrected version of the MAHLI Cal Report is also available from NASA PDS: http://pds-imaging.jpl.nasa.gov/data/msl/MSLMHL_0010/DOCUMENT/MAHLI_TECH_REPT_0001.PDF**	19 Jun 2015	doi:10.13140/RG.2.1.3798.5447 (http://dx.doi.org/10.13140/RG.2.1.3798.5447)
0002	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Interplanetary Cruise and Sols 0–89	22 Jun 2015	doi:10.13140/RG.2.1.4442.6403 (http://dx.doi.org/10.13140/RG.2.1.4442.6403)
0003	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 90-179	25 Jun 2015	doi:10.13140/RG.2.1.2089.5841 (http://dx.doi.org/10.13140/RG.2.1.2089.5841)
0004	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 180-269	25 Jun 2015	doi:10.13140/RG.2.1.4956.7844 (http://dx.doi.org/10.13140/RG.2.1.4956.7844)
0005	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 270-359	26 Jun 2015	doi:10.13140/RG.2.1.3580.5286 (http://dx.doi.org/10.13140/RG.2.1.3580.5286)
0006	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 360-449	26 Jun 2015	doi:10.13140/RG.2.1.4213.3608 (http://dx.doi.org/10.13140/RG.2.1.4213.3608)
0007	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 450-583	21 Sep 2015	doi:10.13140/RG.2.1.3437.6167 (http://dx.doi.org/10.13140/RG.2.1.3437.6167)
0008	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 584-707	11 Dec 2015	doi:10.13140/RG.2.1.3569.0329 (http://dx.doi.org/10.13140/RG.2.1.3569.0329)
0009	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 708-804	14 Dec 2015	doi:10.13140/RG.2.1.3934.6002 (http://dx.doi.org/10.13140/RG.2.1.3934.6002)
0010	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 805-938	14 Dec 2015	doi:10.13140/RG.2.1.2648.4562 (http://dx.doi.org/10.13140/RG.2.1.2648.4562)

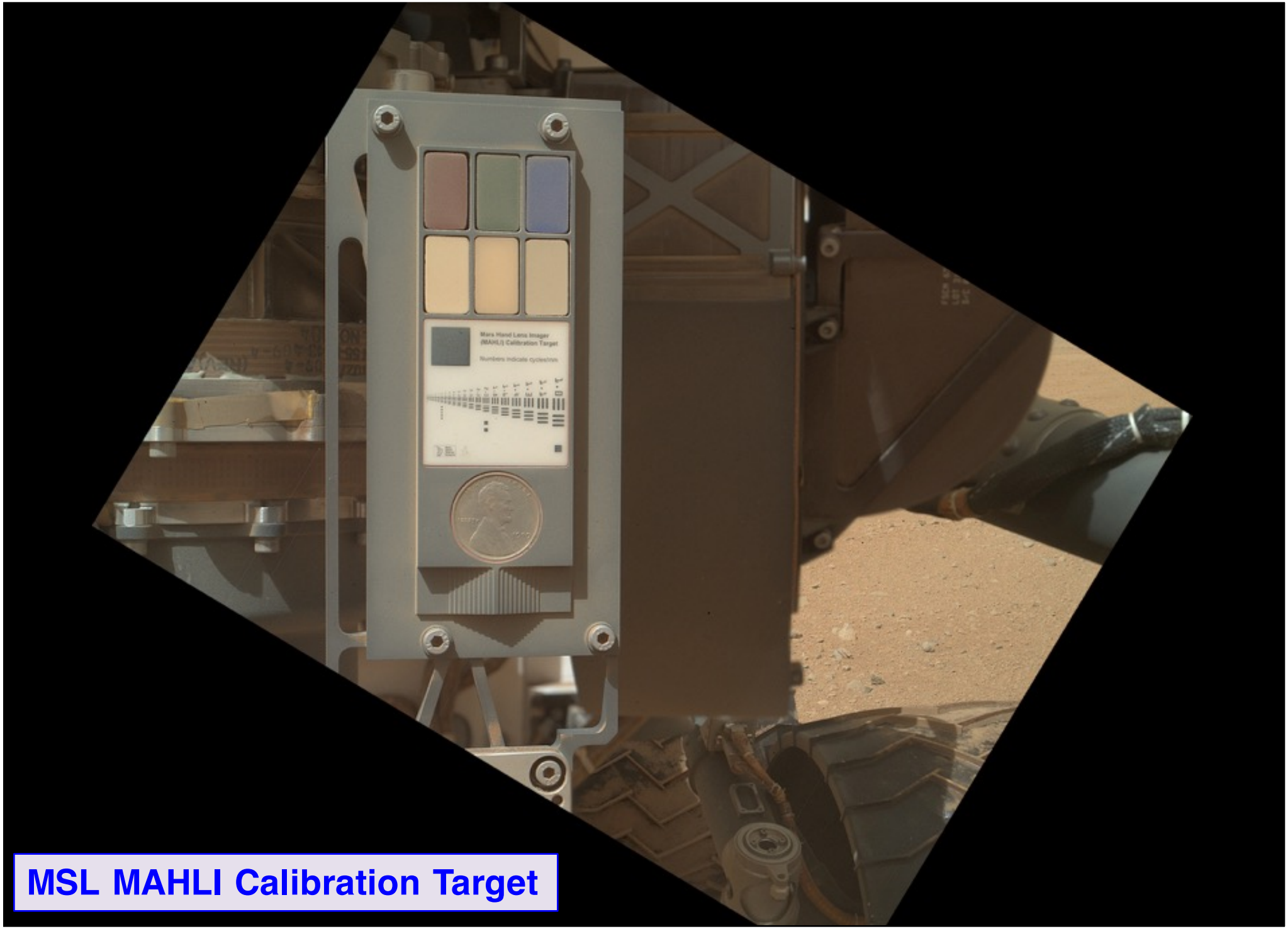
MAHLI Technical Reports

For more information about MAHLI calibration, characterization, image range and scale, focus merge products, etc.

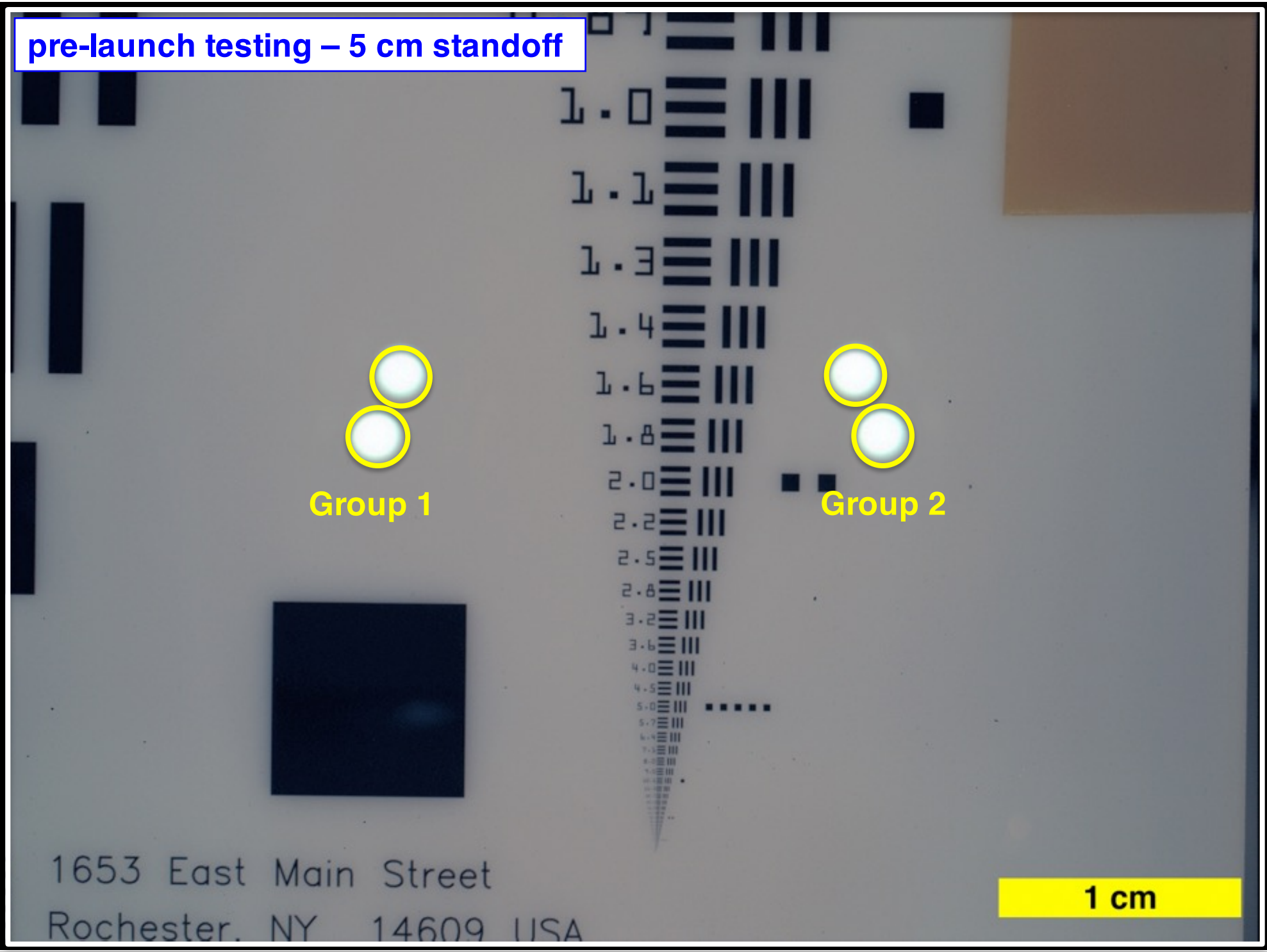
Report	Title	Date	DOI
0011	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory (MSL) Principal Investigator's Notebook: Sols 939–1062	08 Apr 2016	doi:10.13140/RG.2.1.3569.4488 (http://dx.doi.org/10.13140/RG.2.1.3569.4488)
0012	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory (MSL) Principal Investigator's Notebook: Sols 1063–1159	20 May 2016	doi:10.13140/RG.2.1.4605.2721 (http://dx.doi.org/10.13140/RG.2.1.4605.2721)
0013	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 1160–1293	11 Nov 2016	doi:10.13140/RG.2.2.20528.76808 (http://dx.doi.org/10.13140/RG.2.2.20528.76808)
0014	Curiosity's Mars Hand Lens Imager (MAHLI) Mars Science Laboratory Principal Investigator's Notebook: Sols 1294–1417	31 Jan 2017	doi:10.13140/RG.2.2.27370.52163 (http://dx.doi.org/10.13140/RG.2.2.27370.52163)

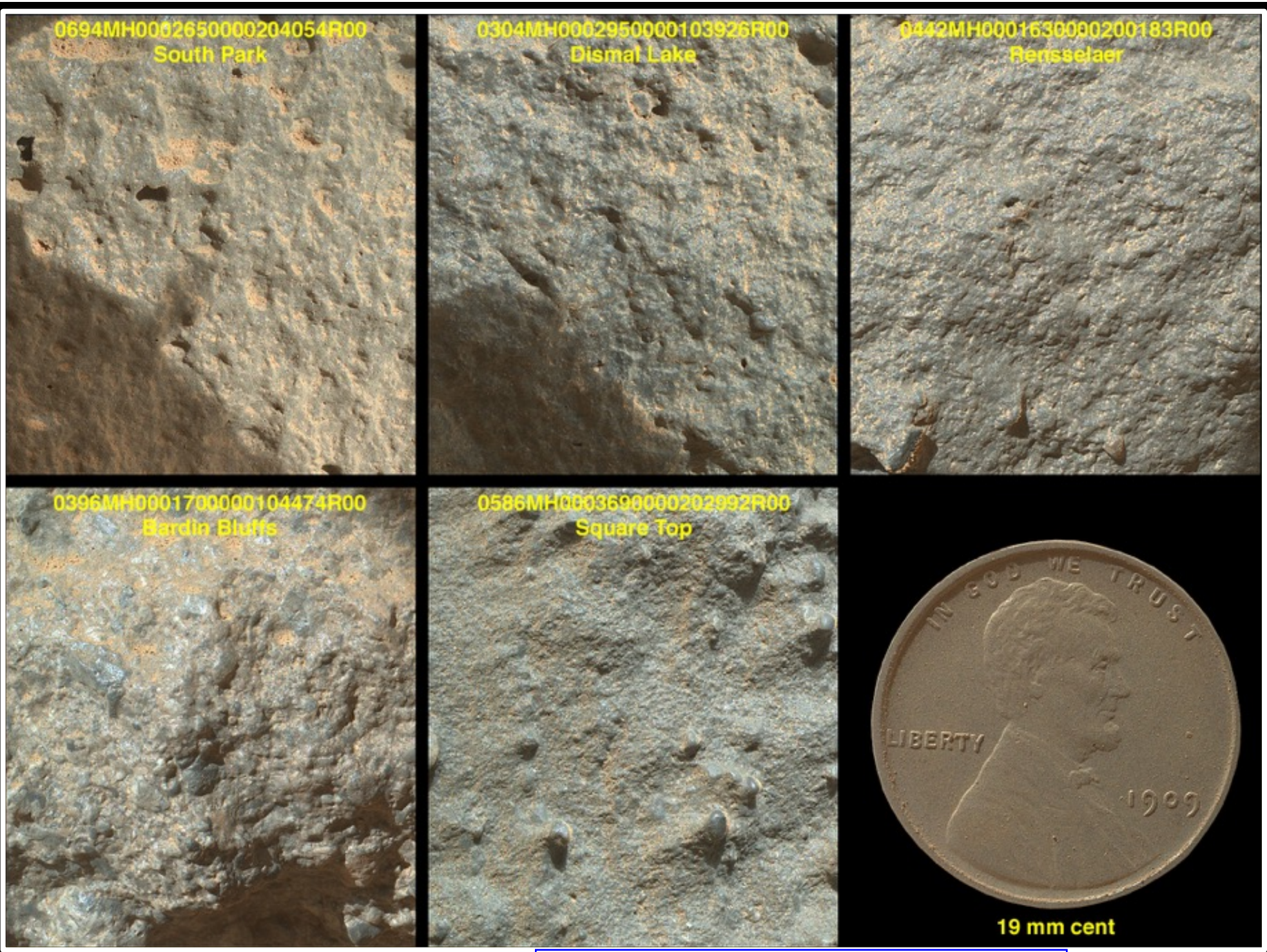
"Principal Investigators Notebook" reports correspond to NASA PDS release cycles but also cannot be completed until all data onboard MAHLI, on Mars, has been either downlinked or deleted onboard. Thus, the report corresponding to the most recent PDS release(s) is/are typically not available because some of the data are still onboard the rover.


contact sensor probe
dust cover
Group 2
White LEDs
Group 1
White LEDs
365 nm
UV LEDs
contact sensor probe

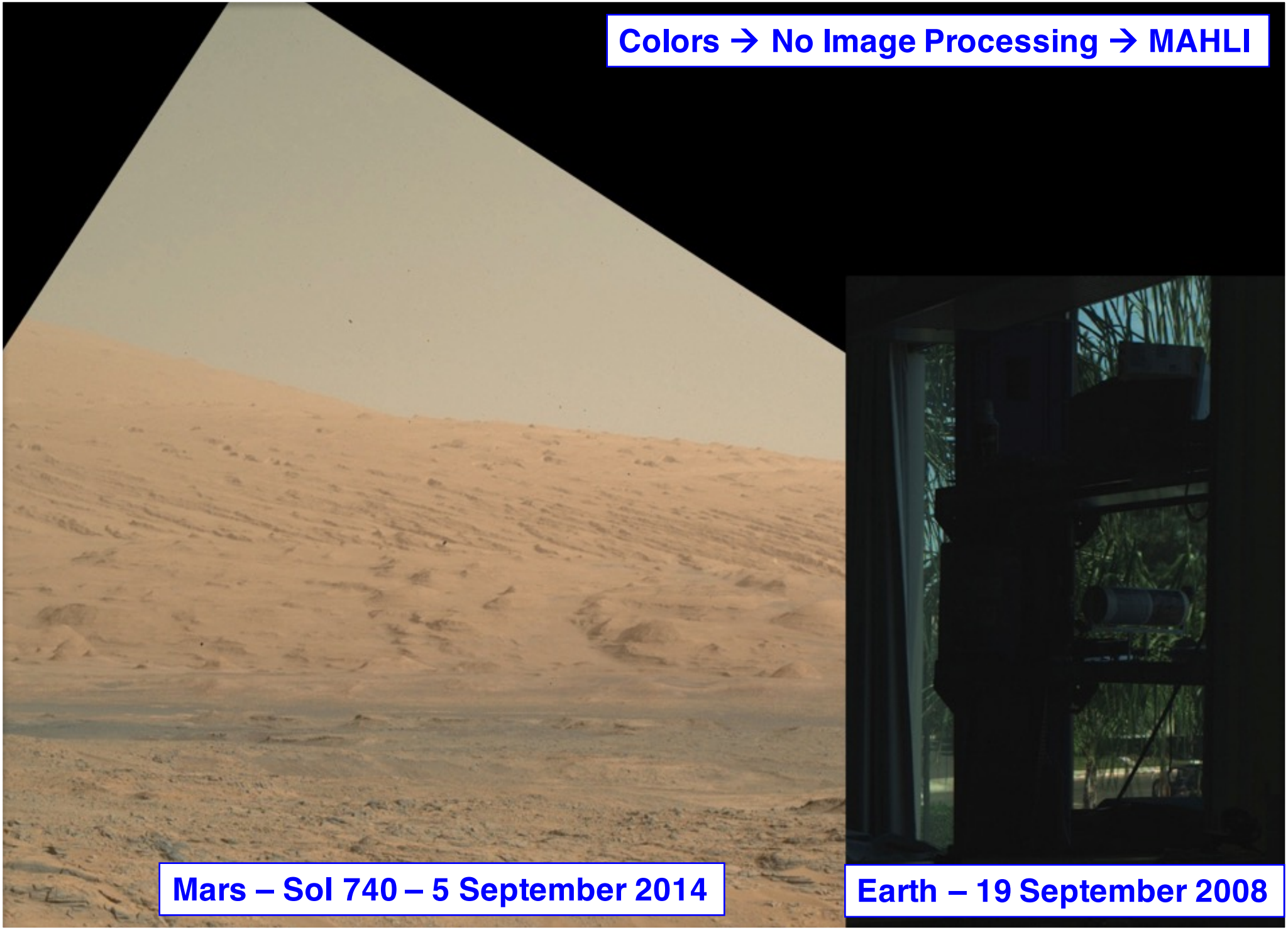


MSL MAHLI Calibration Target


pre-launch testing – 5 cm standoff
Group 1
Group 2
1653 East Main Street
Rochester, NY 14609 USA
1 cm



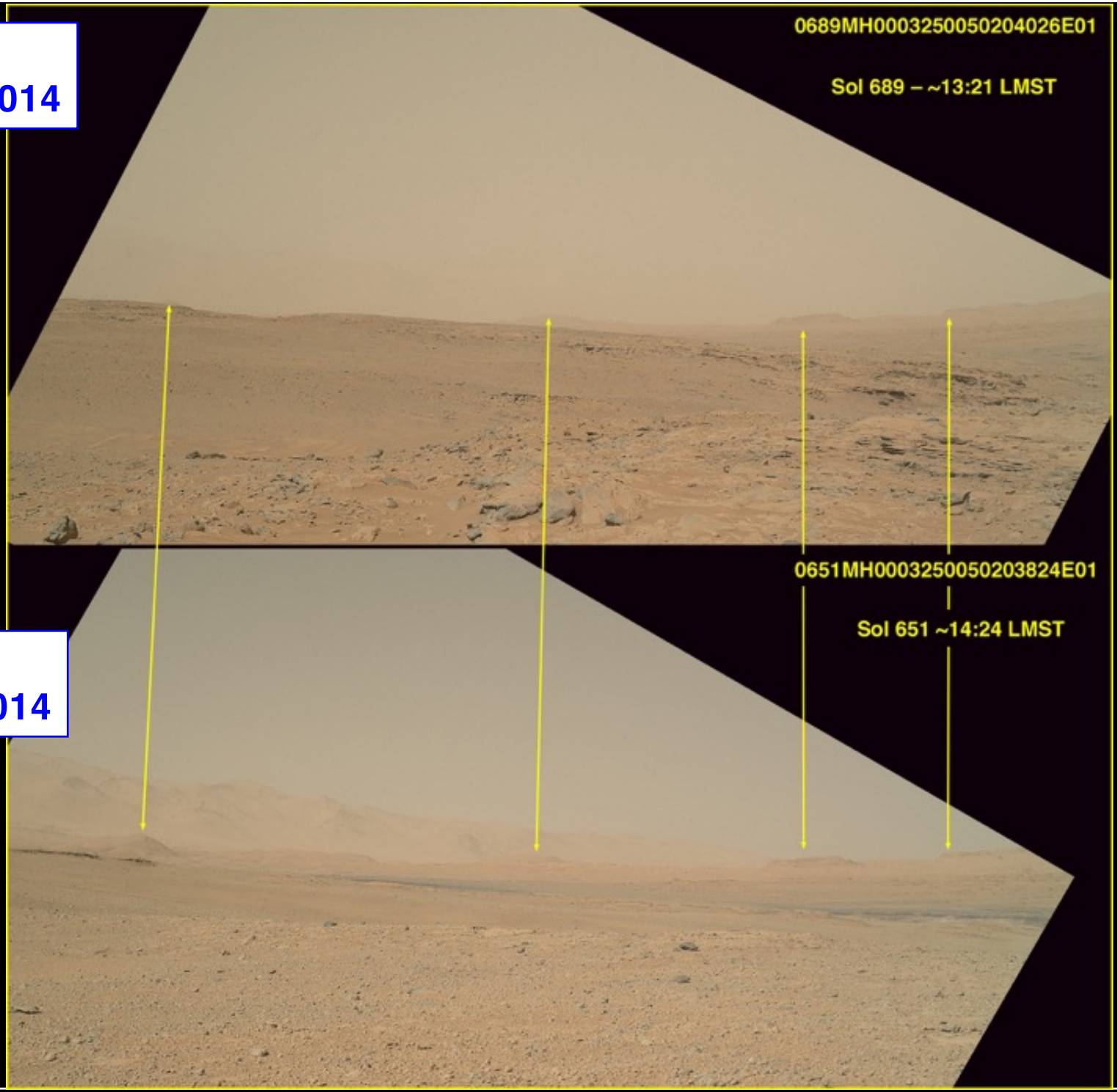
comparing dark, gray, "glinty" sandstones at same scale.


Colors → No Image Processing → MAHLI
Mars – Sol 740 – 5 September 2014
Earth – 19 September 2008

Sol 689
15 July 2014

dusty!

b/c dust storm activity in the region.



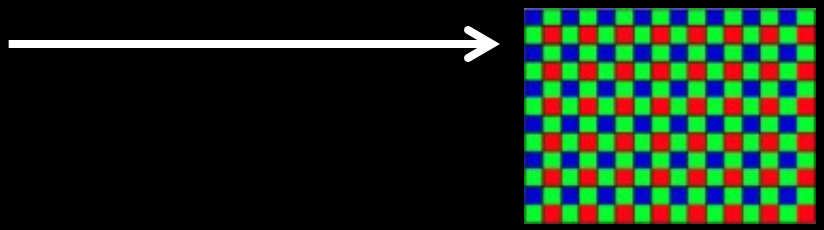
Sol 651
6 June 2014

Science and Support Services

- **Science observing**
  - Images ~14 μm/pixel to > 100 μm per pixel; most common images are 16 to 110 μm/pixel.
  - Close-up color imaging of rocks & regolith targets (grain- and bedding- scale texture, structure,)
  - Stereopairs / 3D mesh
  - Mosaics
  - Nested suites in which lower resolution provides context for higher resolution views.
  - Context support for other contact science and mast-mounted science observations.
  - Curatorial documentation support for extracted sample documentation (vital for making case to return samples).
  - Oblique views of core hole walls for geologic context of extracted samples.
  - "Dog's eye" views under overhanging rock ledges for stratigraphy investigations.
- **Science/Engineering Support**
  - Wheel and undercarriage/belly pan inspections.
  - Robotic Arm Commissioning support (images acquired in ATLO and on Mars)
  - Range-finding support for sample extraction
  - Range-finding support for core hole depth, cuttings pile height, etc.
  - Stereo imaging support for corer placement.
  - Inspections and diagnostics (e.g., of other instruments or rover hardware to understand a problem or monitor dust accumulation)
  - Night illumination options for science or engineering (e.g., on MSL, night imaging is preferred for inspection down CheMin sample inlet).
  - Sample extraction site context, traceable up to HiRISE scale, via "rover self portrait".

Capabilities and Options

- **Focus range 2.1 cm to infinity**
  - pixel scale as high as ~14 μm per pixel; MSL typical highest resolution images 16–21 μm/pixel
- **Color via Bayer Pattern CCD**



  - Can be color-interpolated onboard
- **Sub-framing**
- **Uncompressed, lossless compressed, JPEG lossy**
- **Onboard focus stack merge (up to 8 images)**
- **Night imaging with white and 365 nm LEDs**
- **Stereo, mosaics, nested images via Arm positioning**
- **Autofocus & Manual Focus**
- **Auto-exposure & Manual Exposure**
- **"video" – frame rates likely < 2 per second**

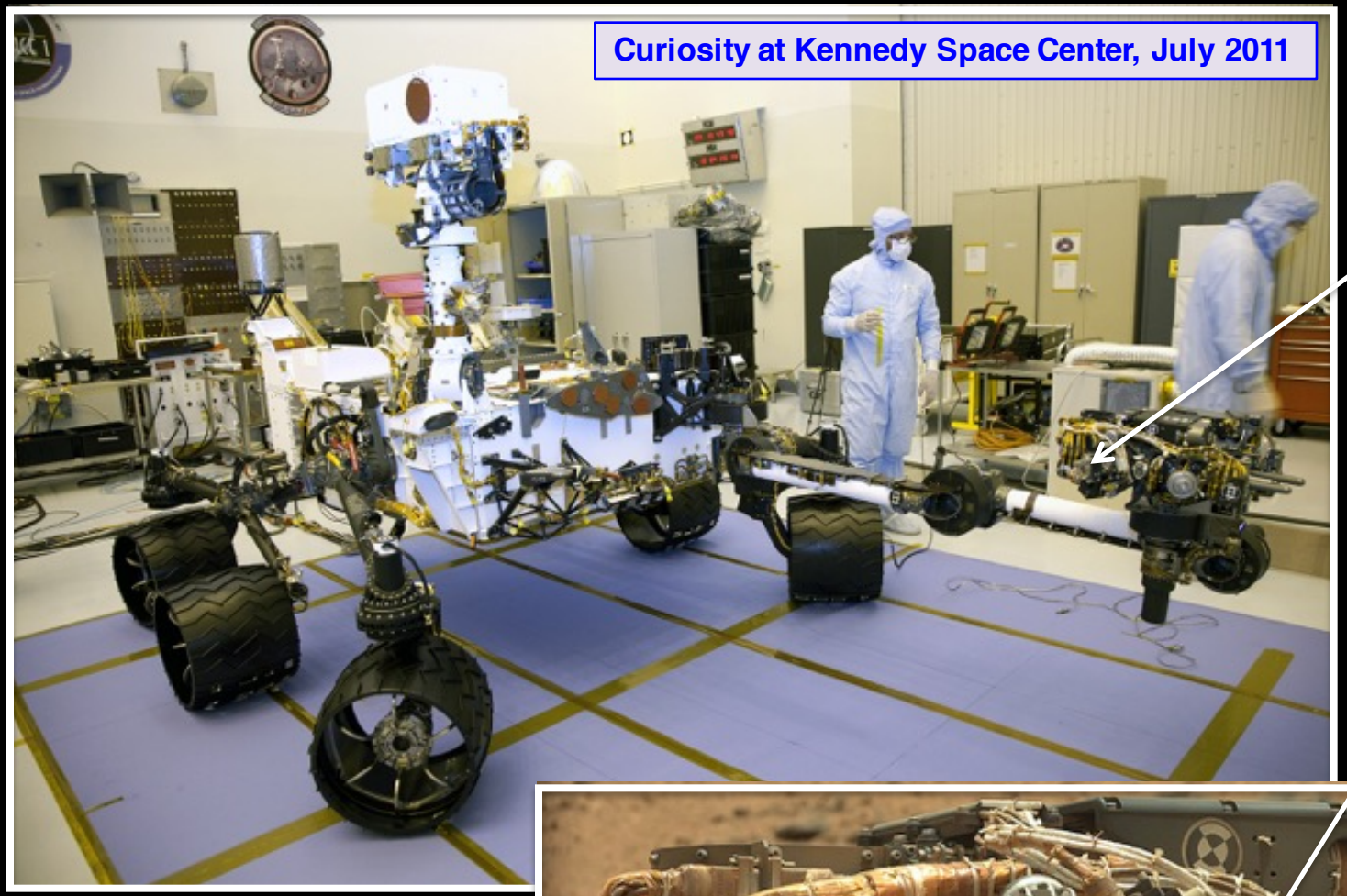
Some MAHLI Characteristics		
bandpass	395–670 nm	
	2.1 cm working distance	**infinity**
depth of field	1 mm	–
field of view (FOV; diagonal)	34°	38.5°
FOV (horizontal 1600 pixels)	26.8°	31.1°
FOV (vertical 1200 pixels)	20.1°	23.3°
instantaneous FOV (IFOV)	402 *μ*rad	346 *μ*rad
focal ratio	f/9.8	f/8.5
effective focal length	18.4 mm	21.4 mm

DEA – Digital Electronics Assembly

- 8 GB flash memory, Very enabling!

- We acquire more images than we return to Earth.
  - Onboard focus merge

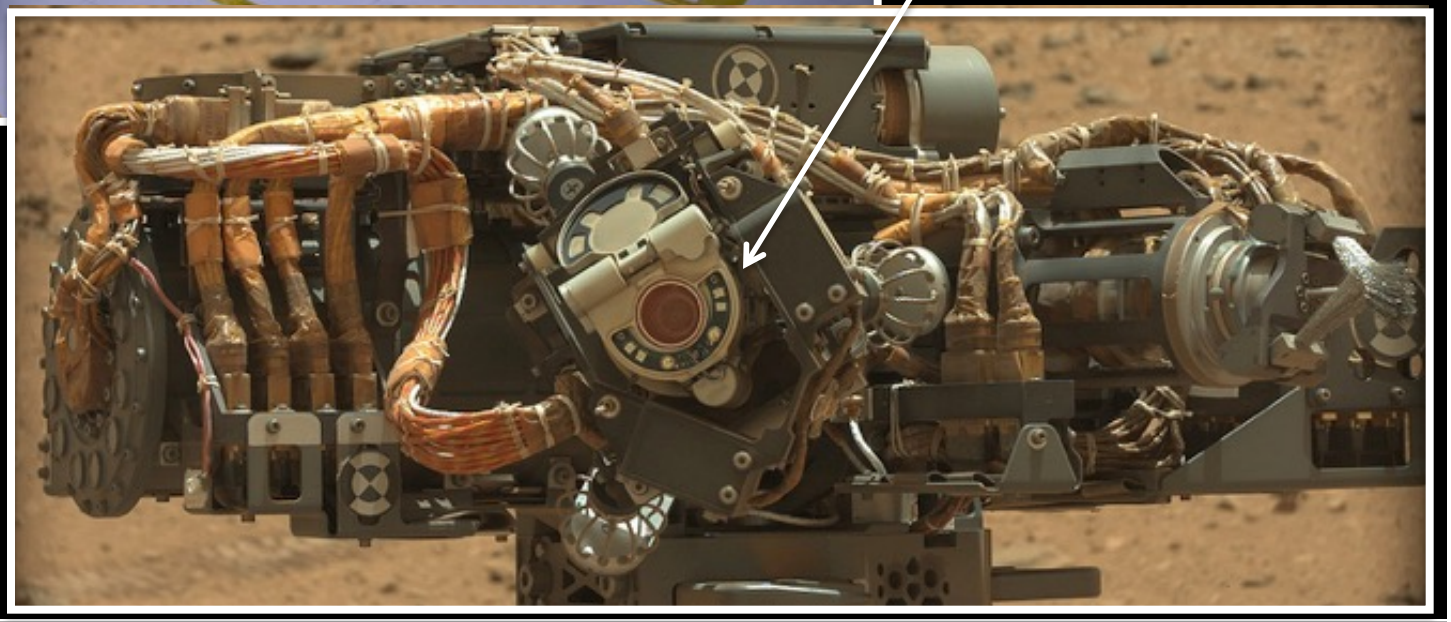
- We often store images uncompressed.
  - if desired, we can return same image more than once with different compression.



Curiosity at Kennedy Space Center, July 2011

NASA photo KSC-2011-5925

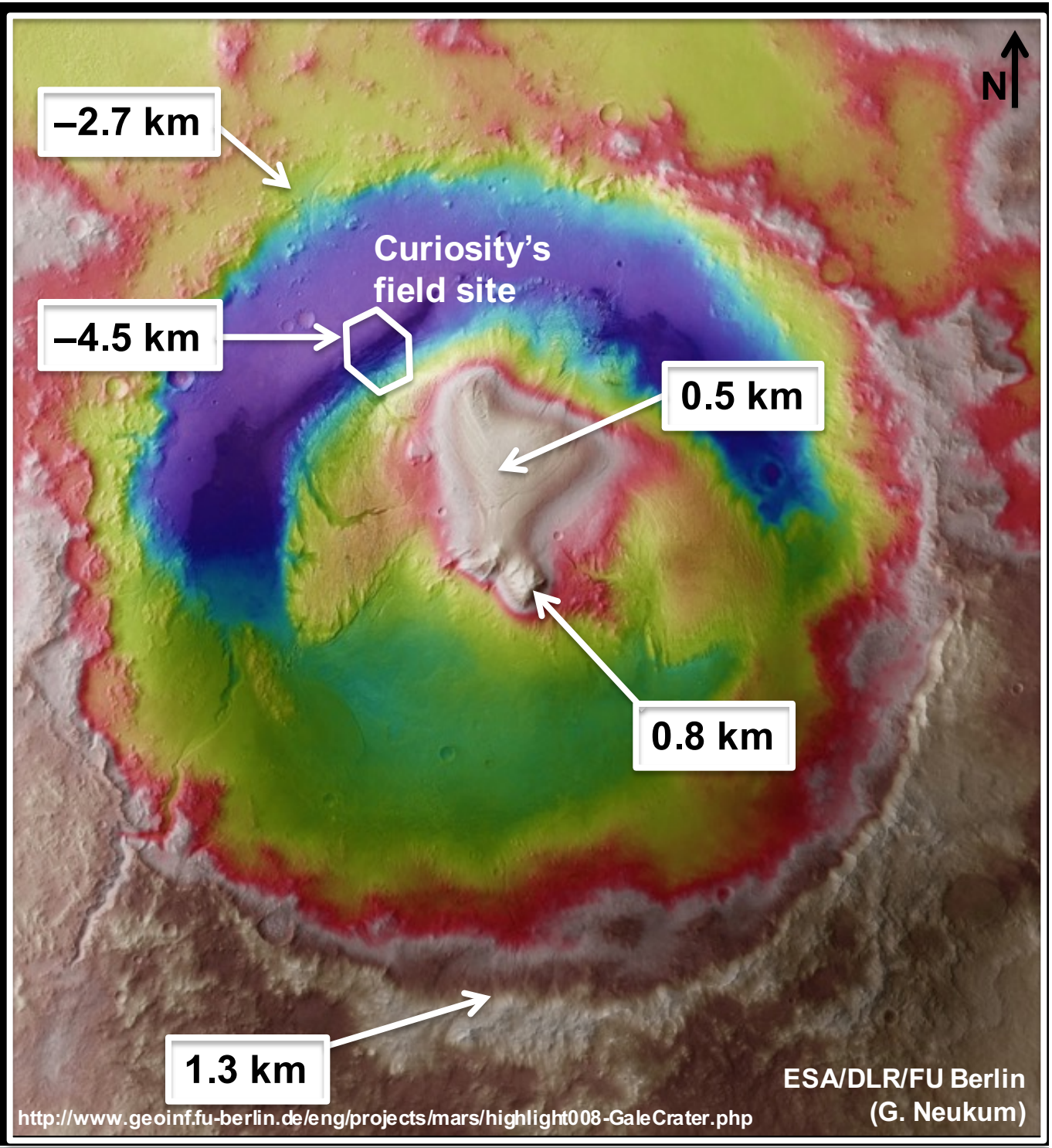
MAHLI camera head is on turret at end of a ~2 m long robotic arm.



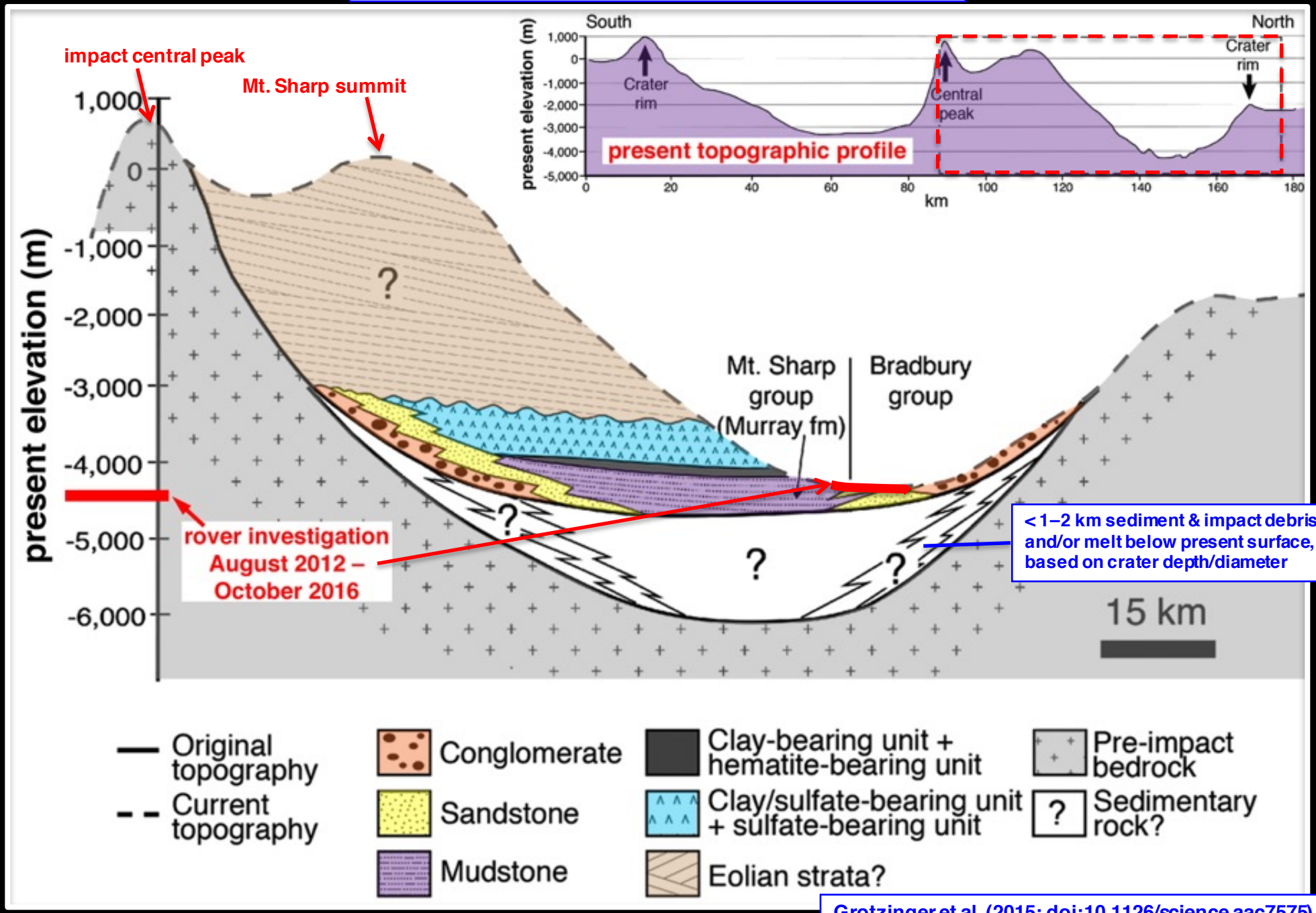
Sol 84 Mastcam-34 image
0084ML0003740000102846E01

Gale Crater

- 5.4°S, 222.3°W
- 155 km diameter
- Mt. Sharp is about 5 km high
- Landing site elevation is near –4.5 km

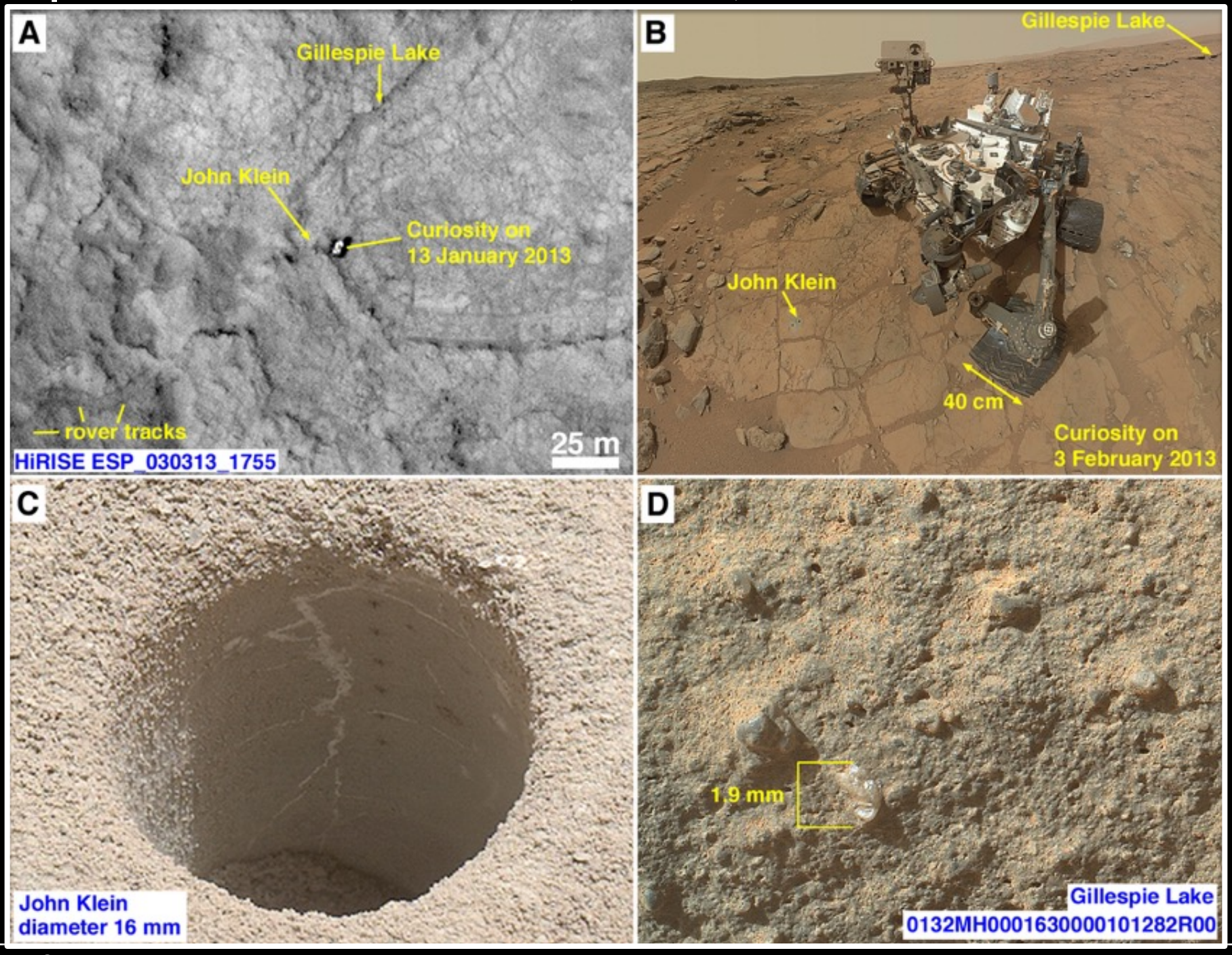


Northern Gale Crater Cross-Section

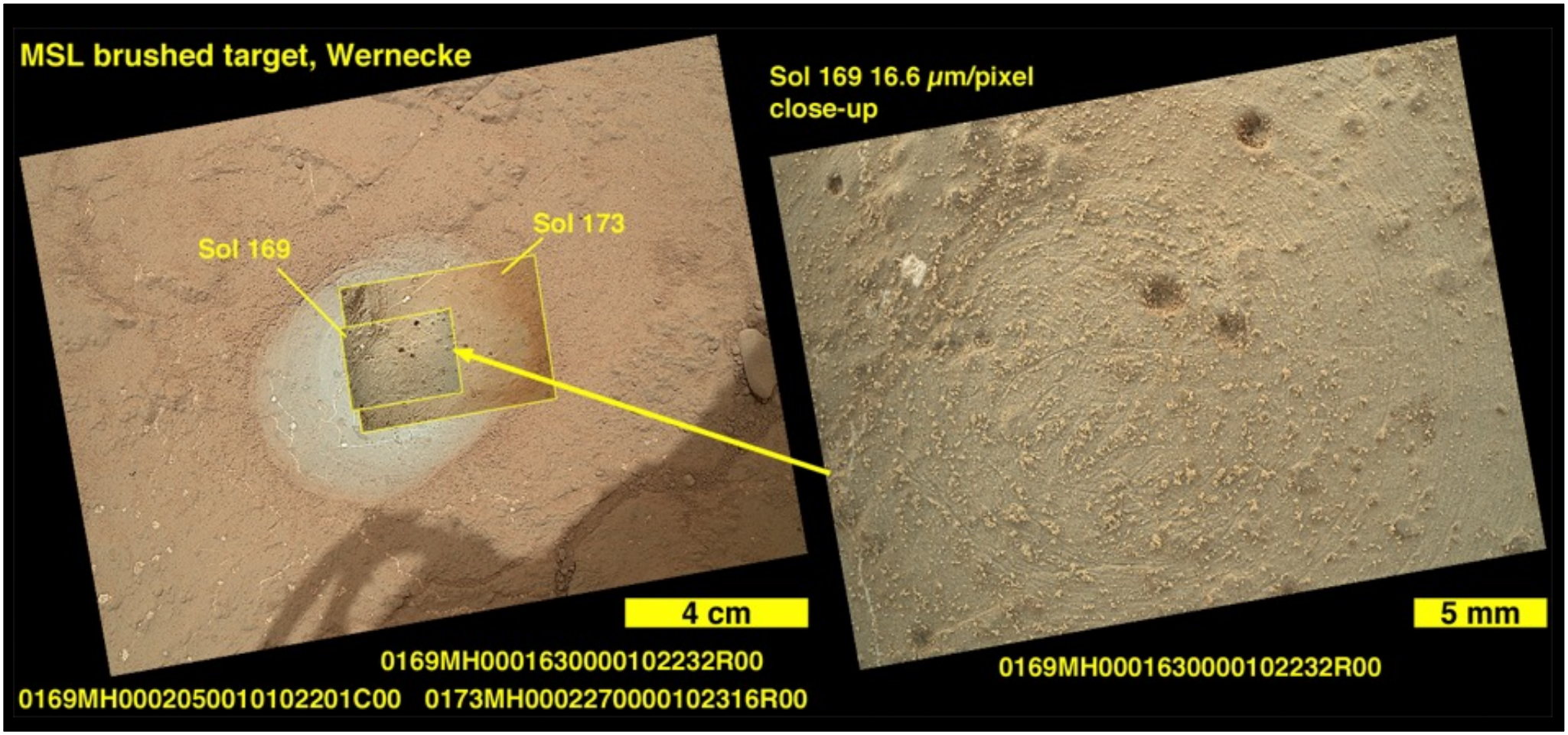


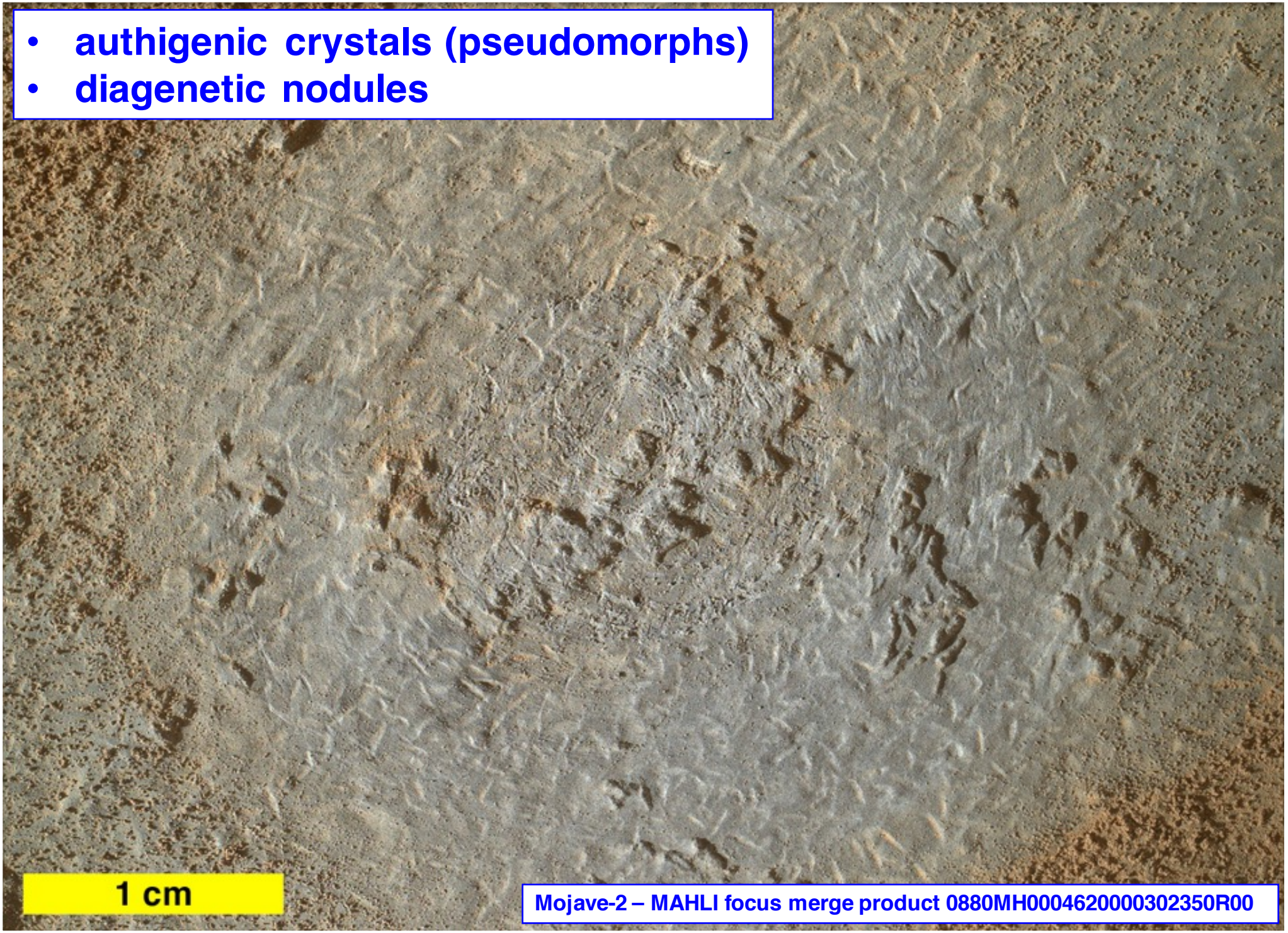
Grotzinger et al. (2015; doi:10.1126/science.aac7575)

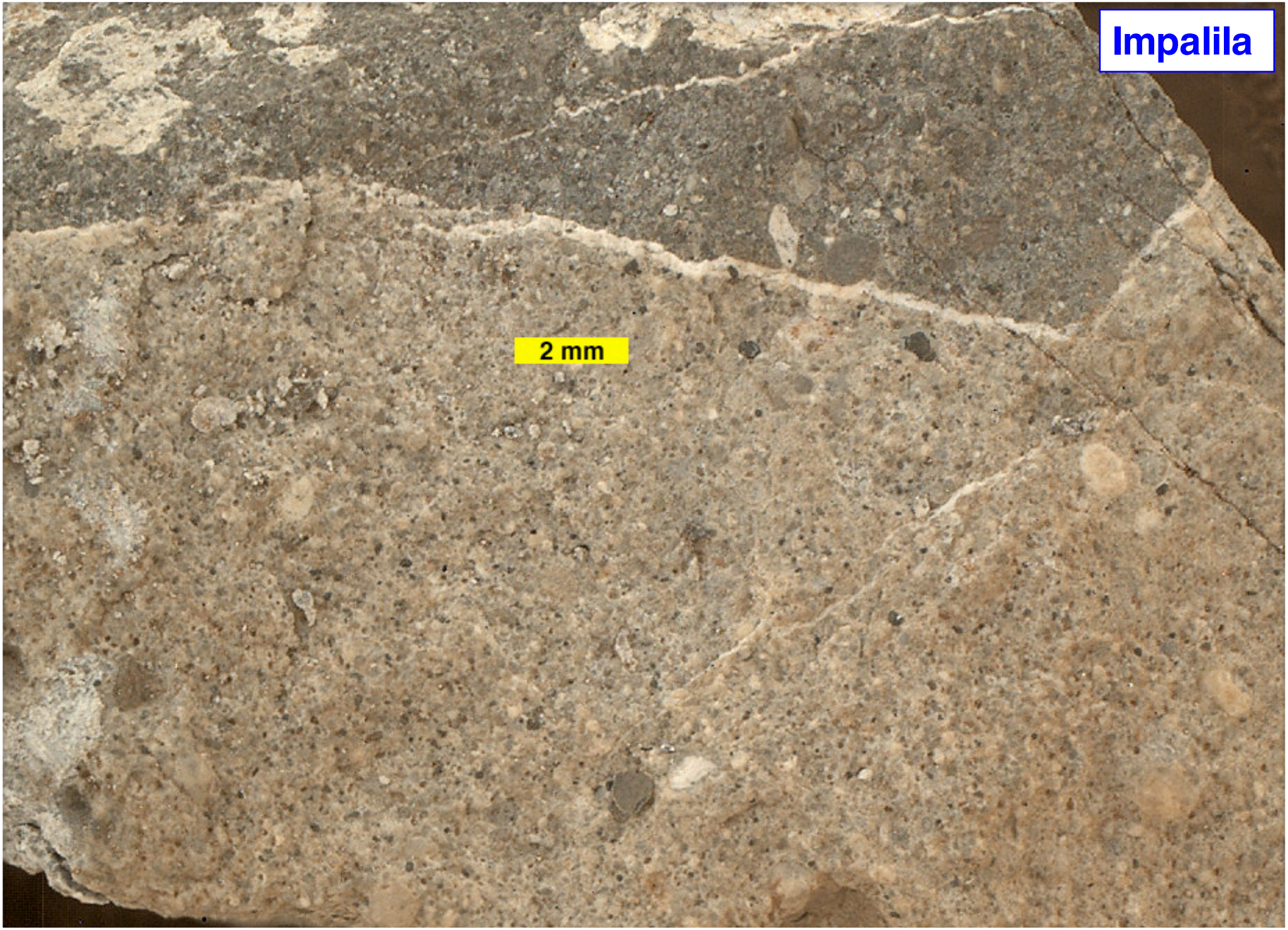
Sample Extraction Site Selection, Context, Curatorial Documentation



Nested Imaging at Various Spatial Scales




• authigenic crystals (pseudomorphs)
• diagenetic nodules
1 cm
Mojave-2 – MAHLI focus merge product 0880MH0004620000302350R00


Impalila
2 mm